Psychology, Economics and Incentives

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Abstract

This PhD. Thesis deals with the effects that psychological phenomena may have on the incentives of agents participating in economic interaction. In particular, I focus on how individuals' preference for certain distributions of welfare among others may affect their effort and other strategic decisions in a variety of contexts. The thesis consists of five chapters. The first one introduces the study. The next two chapters are theoretical and study the effects that aversion to inequity may have on effort decisions. The last two chapters are experimental and show evidence on when welfare comparisons may distort the way experimental subjects play simple games.

Chapter 2 studies optimal contracts when employees are averse to inequity as modelled by Fehr and Schmidt (1999). A "selfish" employer can profitably exploit preferences for equity among his employees by offering contracts which create inequity when employees do not meet the employer's demands. I derive the optimal contract under such circumstances and discuss conditions for inequity aversion to affect the optimal output choice. Similar results are obtained for other types of distributional preferences such as *status-seeking* or *efficiency concerns*.

Chapter 3 studies the mechanics of "leading by example" in teams and it is joint work with Steffen Huck. We show that leadership is beneficial for the entire team when agents dislike effort differentials. We also show how leadership can arise endogenously and discuss what type of leader benefits a team most.

Chapter 4 discusses a laboratory experiment in which subjects played constant sum normal form games and stated beliefs about the frequencies of play by their opponents. Contrary to previous experimental evidence, the results show that game-theoretical predictions work reasonably well: 80% of actions coincided with the Nash equilibrium, subjects were good at predicting the action which was played with highest frequency and 73% of actions were best responses to stated beliefs. The chapter argues that game-theoretical predictions might work well in constant sum games because distributional preferences may not be a factor influencing subjects' decisions in these games.

Chapter 5 shows a follow-up experiment in which we study the robustness of the results in Chapter 4's experiment to sequential play in games with the same payoff matrix as the games in the previous chapter. Although we suspected that sequentiality may trigger some psychological phenomena that may lead subjects to deviate from equilbirium, we find that in our constant sum games the subgame perfect equilibrium predictions work well.

Overall, we conclude that distributional preferences and other types of psychological phenomena have important economic consequences when they affect individuals' incentives. However, as important as it is to acknowledge the effects of psychologial phenomena it is to identify the type of situations in which they change predictions from standard economic theory.

Contents

List of Tables

List of Figures

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Chapter 1

Introduction

During the last 30 years, one of the most lively debates in Microeconomics has been about the acceptance of Behavioural and Experimental Economics. Until recently, most of economic research assumed that people are primarily motivated by material incentives and make decisions in a rational way. However, an increasing amount of research inspired by psychological phenomena and aided by experimental evidence has helped to revise these assumptions. The award in 2002 of the Nobel Prize in Economics to Daniel Kahneman and Vernon Smith confirmed that there was much to be gained in Economics from broadening the motivations that may affect individuals' incentives when engaging in economic interaction.

This PhD. Thesis studies the effects of removing the assumption that individuals are only motivated by their "own" monetary incentives. In particular, we study how important incentive problems are affected when some of the economic agents not only care for their own monetary rewards, but also for the distribution of welfare among others. Our motivation comes from the increasing amount of experimental data that has been explained by other regarding preferences and by the various attempts to model those preferences. Our strategy is two-fold: We first take one of the most prominent modellizations of "distributional" preferences, the model of inequity aversion by Ernst Fehr and Klaus Schmidt, and study its theoretical effects in one of the classical problems of incentive theory, which is how to exert effort from agents in work environments. We study two situations, one in which a principal has to exert effort from several agents (Chapter 2), and one in which there is no principal and two agents decide how to produce some joint work (Chapter 3). We conclude that the fact that agents may care for the reward other agents get for their effort or possibly for the effort other agents exert, has important economic consequences and we analyze their implications. Once we have studied some of the theoretical effects of this particular modellization of distributional preferences, we go back to experiments (Chapters 4 and 5) in order to provide a first step in the wider research programme of identifying the class of games in which standard Game Theory is a good predictor of individuals' behaviour and, in particular, under which circumstances other regarding preferences, both distributional and intentionally driven, do not influence laboratory play.

The theoretical and experimental chapters of this thesis are also linked by the timing in which decisions are made. While in chapters 2 and 4, individuals take actions simultaneously, in chapters 3 and 5 they do it sequentially. This may have implications if individuals care for others' welfare. If actions are taken simultaneously, agents may be more responsive to the distribution of welfare among agents than to the motivations of other agents' actions which causes that distribution, as others' actions are not observed at the time of taking one's own decisions. If, on the other hand, actions are sequential, second movers may respond more to the intentions (and their effects on the final distribution of welfare) signalled by first movers' actions. Thus, first movers may take into account that other consecutive movers may respond to the intentions signalled by their actions. Therefore, the timing of decisions may influence the way individuals care for others' welfare in the sense that they may emphasize whether agents care only for the "distribution" or also for the "reciprocal" effect of their choices. This issue has been central in modelling other regarding preferences. We discuss this issue further in the following chapters.

We here summarize the contents of the remaining chapters:

Chapter 2 studies optimal contracts when employees are averse to inequity as modelled by Fehr and Schmidt (1999). A "selfish" employer can profitably exploit preferences for equity among his employees by offering contracts which create inequity when employees do not meet the employer's demands. We derive the optimal contract under such circumstances and discuss conditions for inequity aversion to affect the optimal output choice. Similar results are obtained for other types of distributional preferences such as "status-seeking" or "efficiency" concerns.

Chapter 3 is joint work with Steffen Huck. We study the mechanics of "leading by example" in teams and show that leadership is beneficial for the entire team when agents dislike effort differentials. We also show how leadership can arise endogenously and discuss what type of leader benefits a team most.

Chapter 4 discusses a laboratory experiment in which subjects played constant sum normal form games and stated beliefs about the frequencies of play by their opponents. Contrary to previous experimental evidence, the results show that game-theoretical predictions work reasonably well: 80% of actions coincided with the Nash equilibrium, subjects were good at predicting the action which was played with highest frequency and 73% of actions were best responses to stated beliefs. The chapter argues that game-theoretical predictions might work well in constant sum games because distributional concerns may not be a factor influencing subjects' decisions in these games.

Chapter 5 shows a follow-up experiment in which we study the robustness of the results in Chapter 4's experiment to sequential play, by designing an experiment in which subjects play sequential games which shared the same payoff matrix as the games in the previous chapter. Although we suspected that sequentiality may trigger some psychological phenomena that may lead subjects to deviate from the unique subgame perfect equilibrium, we find that in these games the subgame perfect equilibrium prediction works even better than the Nash equilibrium prediction in the simultaneous games.

Overall, we conclude that there is clear evidence that individuals care for other individuals' welfare and that this has important economic implications because it affects individuals' incentives. However, as important as it is to acknowledge the effects of psychological phenomena it is to model correctly how these other regarding preferences affect incentives in different situations and to identify the type of situations in which they change predictions from standard economic theory. We here only focus on the effects of a particular type of other regarding preferences in contract theory situations, but this is just one of the many environments in which they can be applied. Likewise, we here offer a first step into the identification of games for which game theory is a good predictor of behaviour and is not influenced by other regarding preferences.

Chapter 2

Inequity Aversion and Team Incentives

2.1 Introduction

One of the most striking results from interview studies with firm managers and employees (Agell and Lundborg (1999), Blinder and Choi (1990), Campbell and Kamlani (1997)) is that employees report to care for the well being of their co-workers and not only for their own. In particular, employees compare co-workers' salaries and performance in the firm with their own. Bewley (1999) shows that 69% of firms' managers interviewed offer formal pay structures because they can create internal equity, which they believe employees care for. Asked why internal equity among employees is relevant for them, 78% of managers answered that it was important for morale and internal harmony and 49% responded that internal equity was key for job performance. This chapter aims to capture how managers should structure reward schemes when their employees care for the distribution of payoffs among their co-workers in a simple model.

We discuss how contracts can exploit distributional preferences to the manager's advantage. Our main result is that a "selfish" principal can devise schemes which exploit agents' preference for equity by offering them more equitable outcomes when managers' demands are met than when they are not. The reason is that equity affects the employees' incentives to work hard and thus, it affects job performance. Following Holmström and Milgrom's (1991) seminal paper, optimal contracts must account for everything employees care about. When agents care for equity the principal has two instruments at his disposal: monetary rewards and equity. By paying rewards which generate more equity when employees perform the effort level desired by the manager than when they do not, the manager does not need to create as much incentives for employees to meet his demands and thus, he can elicit the desired effort levels paying lower rewards than would have been possible had the agents not been inequity averse. Finally, because it may be relatively cheaper to provide incentives for each agent to work, the optimal level of production might change.

Distributional preferences and fairness considerations are one of the most frequent explanations of subjects' behaviour in a wide variety of experiments.[1] In prominent experimental work, Fehr and Schmidt (2000)[2] have argued that fairness lead principals to write incomplete contracts which implement less severe incentives than conventional theory would predict. We develop a simple model in which a principal has to design a reward scheme for two agents who dislike inequity in the way envisaged by F&S. However, contrary to F&S, the principal in our model is not distributional concerned and agents do not care for the principal's welfare, but only for the other agents' and their own. That is, in F&S the comparison of utilities among individuals is vertical (employers compare their welfare to their employees' and vice-versa) while in this chapter it is horizontal (employees compare their welfare only among themselves and the Principal only cares for his own payoffs). Horizontal comparisons among agents seem intuitive. It is natural to assume that welfare comparisons are enhanced by repeated interaction and that employees at the same hierarchical level interact more frequently among themselves than with their superiors. Additionally, it could be argued that employees performing the same task have better information about each agents' cost of effort and find it easier to learn about co-workers' rewards than those of their superiors, making welfare comparisons among employees more accessible. Finally, sociologists have argued that individuals rarely have altruistic feelings for others that have direct authority over their actions.[3] Thus, utility comparisons seem more meaningful among employees on the same hierarchical level than on different levels.[4]

We have chosen the F&S (1999) utility function as a reduced form of social preferences due to its prominence. With simple parameter transformations we can obtain similar results for other types of distributional preferences which might be relevant in the workplace.[5] We later discuss distributional preferences such as *status seeking*

[1] See, for example, Blount and Bazerman (1996), Fehr and Schmidt (1999) and Engelmann and Strobel (2004).

[2] We use F&S in the following to refer to these authors.

[3] See Homans (1950) for a summary.

[4] For example, Dufwenberg and Kirchsteiger (2000) express doubts on which variables would be used to compare employees and employer's utilities. In particular, they ask how meaningful is to compare employees' salaries with firm's profits or the value of the firm's shares.

[5] In particular, our main result would hold for the models proposed by Bolton and Ockenfels (2000), Bazerman, Loewenstein and Thompson (1989), Andreoni and Miller (1998), Cox and Friedman (2002), and the model without intentions by Charness and Rabin (2002).

and *efficiency concerns.* Notice that we do not discuss more complicated forms of social preferences which include reciprocal behaviour and intentions.[6] These preferences could play a role in optimal contract design if we studied repeated interactions in the context of the firm. However, with reciprocal preferences it would be crucial to study the reaction by agents to threats of inequity by the principal. But this reaction would imply that employees care for the intentions of the employer, meaning that vertical considerations would play a role from which we want to abstract.

Our model is very stylized. First, we focus on incentive compatibility, not on participation. We assume that the participation constraint does not bind and thus both agents work for the firm. In particular, we normalize the utility of being in the firm to zero and we assume that the utility derived from not being in the firm is below this value. As we do not explicitly model an outside option its utility could take any value. We simply assume it is lower than when working in the firm. This could be justified for different reasons: search costs of finding a different job, good matching with employers, specific human capital, disutility of unemployment or the existence of minimum rewards. But in particular, notice that if agents are still inequity averse when taking the outside option, utility when leaving the firm could be lower than inside the firm, as agents would obtain disutility for other agents left behind. As the reference group in the outside option is unclear and it is probably context dependent, we omit the analysis of the participation constraints by assuming they do not bind. Our results are thus limited to this case. Another possible interpretation of our model is that the rewards in the model are not agents' wages but a bonus offered to perform an extra activity. Thus, while the wage would take care of the participation constraint, the extra bonus provides incentives to perform an extra effort. In that view, our results should be interpreted as implying that bonuses might not need to cover employees' cost of performing an extra effort when they feel *envy* or *guilt* towards their peers. This interpretation is close to empirical effects observed under real team and relative performance contracts (Bandiera et al., (2004)).

Second, we do not consider an uncertain production environment. In our model output is deterministic and informative about the effort level performed by each agent. We want to show how inequity aversion in itself changes the optimal contract, without adding uncertainty. In a paper independently written at the same time as this chapter, Itoh (2004) uses a model where output is uncertain and shows that inequity aversion calls for optimal contracts to specify both agents' rewards under all possible circumstances, which also occurs in our model. However, Itoh's mechanism is different from ours. In his model, each agent undertakes a different project and the principal writes the contract such that both agents always perform high effort. More equal (or

[6] For good surveys on social preferences see Sobel (2000) and Fehr and Schmidt (2002b).

more unequal) rewards are used in Itoh's paper to compensate for the risk of one of the agents' projects failing. In our study, inequity aversion determines whether it is optimal or not to form teams in which both agents perform high effort and we show how unequal rewards must be offered off-equilibrium to optimally exploit inequity aversion. Both approaches are complementary.

Other papers have simultaneously studied inequity aversion in the contest of the firm. Englmaier and Wambach (2002) study the interaction between an inequity averse agent who compares himself with a *selfish* principal. Grund and Sliwka (2002) study welfare comparisons in tournaments. Cabrales and Calvó-Armengol (2002) use inequity aversion among employees to justify skill segregation. Huck and Rey Biel (2002) look at teams formed by inequity averse agents when there is no principal.

The rest of the chapter is organized as follows. Section 2.2 describes the model. Section 2.3 characterizes the optimal contract when agents have standard preferences. Section 2.4 characterizes the optimal contract when agents are inequity averse. Section 2.5 discusses optimal contracts when distributional preferences take other forms, such as *status seeking* and *efficiency concerns.* Section 2.6 concludes. The Appendices contain the proofs and show two relevant examples.

2.2 The Model

There are a Principal and two agents $i, j \in \{1, 2\}$ with $i \neq j$. Agents can either work or not work. If both agents work, production is normalized to 1 (joint production). If only agent i works, production is q_i, where $0 < q_i < 1$ (individual production by agent i). If no agent works, production is 0. Output is observable. Effort is verifiable and contractible.

The cost for each agent of working is $c_i > 0$. The cost of not working is normalized to 0. A complete contract specifies the rewards offered to both agents for all possible output levels. In order to standardize notation, assume the principal offers rewards $\{w_1, w_2\}$ to agents 1 and 2 respectively when both agents work, $\{w_1^1, w_2^1\}$ when agent 1 individually works and $\{w_1^2, w_2^2\}$ when agent 2 individually works. If no agent works, rewards are zero.[7]

The structure of the game is as follows: the Principal offers rewards for all possible production levels, agents decide simultaneously whether or not to work and, once production is realized, promised rewards for the output level produced are paid. Following Ma et al. (1988) we look at the contract such that the implemented production level is the unique equilibrium of the game played by the agents.[8] As the game is 2x2, the

[7]This is implied by assumptions (R1) and (R2) below.

[8]We do so in order to avoid the problem in Demski and Sappington (1984) that given an optimal

contract that implements a unique equilibrium makes the game played by the agents dominance solvable.[9]

The Principal seeks to maximize its profit, that is, production minus rewards paid.[10] Given the minimum rewards needed to be paid in equilibrium to implement each production level and the productivity parameters (q_i and c_i), the Principal designs the contract that implements the output level which maximizes its profit. Two different specifications for the agents' utility functions will be considered in Sections 2.3 and 2.4. These specifications will be explained later.

The structure of the game is known by the principal and the agents and, in particular, they both know the rewards offered, the production level each agent achieves if working individually and each agents' cost of effort. Agents cannot communicate among themselves.

Assume the following.

(C) *The sum of working agents' costs of effort is smaller than the output produced.*

$$0 \leq c_1 < q_1,$$
$$0 \leq c_2 < q_2,$$
$$c_1 + c_2 < 1.$$

(R1) *Agents' Limited liability: Negative rewards are not possible.*

$$\begin{aligned} w_1, w_1^1, w_1^2 &\geq 0, \\ w_2, w_2^1, w_2^2 &\geq 0. \end{aligned}$$

(R2) *Rewards are paid from output produced.*

$$\begin{aligned} w_1 + w_2 &\leq 1, \\ w_1^1 + w_2^1 &\leq q_1, \\ w_1^2 + w_2^2 &\leq q_2. \end{aligned}$$

contract there may exist another pair of equilibrium strategies whose outcome, from the agents' point of view, pareto dominates the equilibrium outcome which the principal wants to implement and thus, the contract may not implement the optimal output level.

[9] As we will see below, in all but one case, equilibrium uniqueness does not require to pay in equilibrium a higher sum of rewards than required to obtain the optimal output level as one of the possible equilibria of the game played by the agents. Rewards offered off-equilibrium, however, may differ depending on whether the equilibrium implemented is unique or not.

[10] Assuming the prize of production is one and all production is sold.

Assumption (C) implies that there always exists a surplus above the cost of effort performed. Assumption (R1) is a limited liability constraint restricting how much the principal can monetarily punish agents for not performing effort. Assumption (R2) is a budget constraint for the Principal. Notice that for contracts to be credible, assumptions (R1) and (R2) must also hold for rewards offered off the equilibrium of the game played by the agents.[11]

2.3 Optimal contract with standard agents

In this section we derive the optimal contract when agents are standard. Standard agents maximize their "direct utility" which is equal to the reward they are offered minus the cost of effort they perform. Below we show each agents' direct utility in the game depending on the actions taken by both agents and the rewards offered by the Principal.

		Agent 2	
		Work	Not Work
Agent 1	Work	$w_1 - c_1$, $w_2 - c_2$	$w_1{}^1 - c_1$, $w_2{}^1$
	Not Work	$w^2{}_1$, $w^2{}_2 - c_2$	0 , 0

We first solve for the optimal contract necessary to implement each production level and then, given the optimal rewards, we derive conditions for each production level to be optimal. Although the solution of this problem is straightforward, we solve it here as reference for the following section.

2.3.1 Optimal contract to implement individual production with standard agents

We here find the optimal contract to implement individual production by agent 1 as the unique equilibrium of the game played by the agents.[12] The problem is the following:

[11] As it will be clear below, we impose budget constraints off-equilibrium to show the interesting interplay between creating inequity off-equilibrium via *envy* or *guilt*. Without budget constraints, the Principal could offer infinite rewards to one agent off-equilibrium, maximizing the other agent's *envy* when not performing the optimal production level.

[12] The optimal contract to implement individual production by agent 2 is symmetric.

-The principal maximizes its profit:

$$Max\ q_1 - w_1^1 - w_2^1$$

subject to:

- Assumptions (R1) and (R2).
- Agent 1 prefers to work when agent 2 does not work: $w_1^1 - c_1 \geq 0$.
- Agent 2 prefers not to work when agent 1 works: $w_2^1 \geq w_2 - c_2$.

For the game to have a unique equilibrium with the lowest total reward cost paid by the principal, the following constraints are also necessary:

- Agent 2 strictly prefers not to work when agent 1 works: $w_2^1 > w_2 - c_2$.
- Agent 1 strictly prefers to work when agent 2 works: $w_1 - c_1 > w_1^2$.
- Agent 2 strictly prefers to work when agent 1 does not work: $w_2^2 - c_2 > 0$.

The objective function and the restrictions are linear. Thus, the solution is straightforward:

$$\begin{array}{ll} w_1 \in (c_1, 1 - w_2] & w_2 \in [0, c_2), \\ w_1^1 = c_1 & w_2^1 = 0, \\ w_1^2 \in [0, w_1 - c_1) & w_2^2 \in [c_2, q_2 - w_1^2) \end{array}$$

The optimal contract is such that in equilibrium, the agent who individually works is exactly compensated for his cost of effort ($w_1^1 = c_1$) while the agent who does not work is paid no reward ($w_2^1 = 0$). The principal's profit in the unique equilibrium of the game is then equal to $q_1 - c_1$. Off-equilibrium rewards do not affect the principal's profits and thus, they can take any value in the intervals shown.

2.3.2 Optimal contract to implement joint production with standard agents

We here find the optimal contract to implement joint production as the unique equilibrium of the game played by the agents. The problem is the following:

-The principal maximizes its profit:

$$Max\ 1 - w_1 - w_2$$

subject to:

- Assumptions (R1) and (R2).
- Both agents prefer to work when the other agent works: $w_i - c_i \geq w_i^j$ for $i, j = 1, 2$, $i \neq j$.

For the game to have a unique equilibrium with the lowest total reward cost paid by the principal, the following constraints are also necessary:

- Let $w_i - c_i > w_i^j$ and $w_j - c_j \geq w_j^i$ then $w_i^i - c_i < 0$ and $w_j^j - c_j > 0$.

Again, the objective function and the restrictions are linear so the solution is straightforward:

$$\begin{array}{ll} w_i = c_i + \varepsilon & w_j = c_j, \\ w_i^i \in [0, c_i) & w_j^i = 0, \\ w_i^j = 0 & w_j^j \in (c_j, q_j], \end{array}$$

for $i, j = 1, 2,\ i \neq j$.

Notice that for joint production to be the unique equilibrium, it is necessary to add a negligible positive quantity $\varepsilon \to 0$ to one of the agents' equilibrium rewards. As it happened with individual production, in an equilibrium with joint production agents are exactly compensated for their cost of effort.[13] Rewards offered off the equilibrium of the game are such that agents do not deviate from the unique level of production the principal finds optimal to implement.[14] The principal's profits in the unique equilibrium of the game are equal to $1 - c_1 - c_2$.

2.3.3 Optimal production level with standard agents

Given that in equilibrium agents are paid a reward exactly equal to their cost of effort when they work, the principal decides the optimal production level by comparing its profits when joint production is implemented $(1-c_1-c_2)$ with its profits when individual production by the agent with highest productivity net of his cost is implemented ($q_i - c_i$ for $q_i - c_i \geq q_j - c_j$ and $i, j = 1, 2, i \neq j$). The conditions for each level of production to be optimal are:

- Individual Production by agent 1 if and only if $q_1 - c_1 \geq q_2 - c_2$ and $q_1 \geq 1 - c_2$,
- Individual Production by agent 2 if and only if $q_1 - c_1 < q_2 - c_2$ and $q_2 \geq 1 - c_1$,
- Joint Production if and only if $q_1 < 1 - c_2$ and $q_2 < 1 - c_1$.

Figure 1 draws these conditions.

[13] We assume ε to be small enough such that profits and conditions for joint production to be optimal are not affected.

[14] Notice that the "most natural" contract, paying both agents a reward equal to their cost of effort when they work and offering no reward to an agent who does not work, does not implement a unique equilibrium in the subgame, as no production would also be an equilibrium.

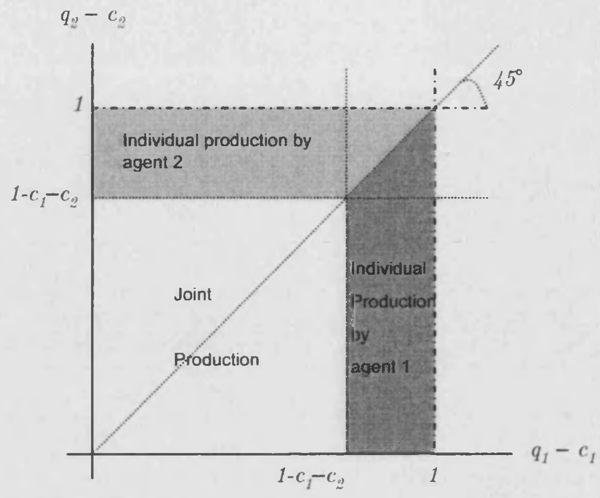


Figure 1: Optimal output level with standard agents.

2.4 Optimal contract with inequity averse agents

In this section we derive the optimal contract when agents are inequity averse. We follow F&S's (1999) model of inequity aversion by adapting their utility function to our context with two agents. Inequity averse agents' utility function is U_i^{FS} where:

$$U_i^{FS} = U_i - \alpha \max\left[U_j - U_i, 0\right] - \beta \max\left[U_i - U_j, 0\right] \quad \text{for } i, j = 1, 2, \quad i \neq j,$$

where, as before, U_i is each agent's "direct utility" and is equal to rewards offered minus the cost of effort performed.[15]

Assume the following:

(U1) *Agents dislike inequity:*

$$\alpha \geq 0,$$

$$\beta \geq 0.$$

(U2) *Agents care more for their own direct utility than for inequity:*

$$\alpha < 1 \text{ and } \beta \leq \frac{1}{2}.$$

[15] While F&S's original formulation refers to agents comparing "payoffs", other authors using their preferences in our context assume that only wages enter into welfare comparisons but not the costs of effort (Grund and Sliwka (2002), Itoh (2004)). Our results hold with this alternative specification although contract design is different and more interesting issues appear when costs of effort enter the comparison. Ultimately, this is an empirical question that may be context dependent. A first experimental study of this issue is Königstein (2000) who confirms that welfare comparisons are context dependent.

Assumption (U1) imposes inequity *aversion.* Agents derive disutility from direct utilities being unequal. In the following, α refers to *negative inequity aversion* or *envy* (dislike to being worse off than your peers), while β refers to *positive inequity aversion* or *guilt* (dislike to being better off than your peers). We assume that parameters α and β are the same among agents for simplicity.[16] Assumption (U2) implies that agents care more for their own direct utility than for the comparison with the other agent's direct utility. F&S allow for $\alpha > 1$. We assume $\alpha \leq 1$ to show that even if inequity aversion is not dominant, its effects on the optimal contract design can still be substantial. Notice that $\beta \leq \frac{1}{2}$ is also necessary for own direct utility to be dominant. Otherwise, agents would be willing to transfer rewards to the other agent ex-post. Additionally, F&S impose $\beta \leq \alpha$, which we do not for generality.

Below we show each agent's utility in the game depending on the actions taken and the rewards offered by the principal to both agents. Notice than when agents are inequity averse, agent i's direct utility is an externality in agent j's utility.

		Agent 2: Work	Agent 2: Not Work
Agent 1	Work	$w_1-c_1-\alpha\max[w_2-c_2-w_1+c_1,0]-\beta\max[w_1-c_1-w_2+c_2,0]$, $w_2-c_2-\alpha\max[w_1-c_1-w_2+c_2,0]-\beta\max[w_2-c_2-w_1+c_1,0]$	$w_1^1-c_1-\alpha\max[w_2^1-w_1^1+c_1,0]-\beta\max[w_1^1-c_1-w_2^1,0]$, $w_2^1-\alpha\max[w_1^1-c_1-w_2^1,0]-\beta\max[w_2^1-c_2-w_1^1,0]$
	Not Work	$w_1^2-\alpha\max[w_2^2-c_2-w_1^2,0]-\beta\max[w_1^2-w_2^2+c_2,0]$, $w_2^2-c_2-\alpha\max[w_1^2-w_2^2+c_2,0]-\beta\max[w_2^2-c_2-w_1^2,0]$	0 , 0

In the following subsections we study how the principal can exploit this externality to its advantage. We proceed as before, first solving for the optimal contract for each production level and then discussing the conditions for each production level to be optimal.

2.4.1 Optimal contract to implement individual production with inequity averse agents

As in the previous section, we derive the contract which implements individual production by agent i when both agents are inequity averse. Define ICC_i^{ind} for $i = 1, 2$ as the constraints that make individual production by one agent incentive compatible and ICC_i^{indU} as the constraints required for individual production to be the unique equilibrium of the game played by the agents. The problem is the following:

[16] We focus on asymmetries in productivity parameters instead than on social preferences because they should be more easily observable and measurable.

-The principal maximizes its profit:

$$Max\ q_i - w_i^i - w_j^i$$

subject to:

- Assumptions (R1), (R2).
- (ICC_i^{ind}): $w_i^i - c_i - \alpha \max[w_j^i - w_i^i + c_i, 0] - \beta \max[w_i^i - c_i - w_j^i, 0] \geq 0$.
- (ICC_j^{ind}): $w_j^i - \alpha \max[w_i^i - c_i - w_j^i, 0] - \beta \max[w_j^i - w_i^i + c_i, 0] \geq$ $w_j - c_j - \alpha \max[w_i - c_i - w_j + c_j, 0] - \beta \max[w_j - c_j - w_i + c_i, 0]$.

For the game to have a unique equilibrium with the lowest total reward cost paid by the principal, the following constraints are also necessary:

- The inequality in condition (ICC_j^{ind}) is strict.
- (ICC_i^{indU}): $w_i - c_i - \alpha \max[w_j - c_j - w_i + c_i, 0] - \beta \max[w_i - c_i - w_j + c_j, 0] >$ $w_i^j - \alpha \max[w_j^j - c_j - w_i^j, 0] - \beta \max[w_i^j - w_j^j + c_j, 0]$.
- (ICC_j^{indU}): $w_j^j - c_j - \alpha \max[w_i^j - w_j^j + c_j, 0] - \beta \max[w_j^j - c_j - w_i^j, 0] > 0$.

We describe a property of the solution to this problem in the following *Proposition.*

Proposition 2.1 *To implement individual production when agents are inequity averse rewards paid in the equilibrium of the game played by the agents are the same as with standard agents ($w_i^i = c_i$ and $w_j^i = 0$).*

Intuitively, the agent who individually works in the equilibrium of the game must prefer to work than not to work, given that the other agent is not working. Due to budget constraints (R2), agents are not paid when they both do not work and thus, the utility of both agents when they both do not work is the same and equal to zero. Inequity generates disutility and because there is no inequity when both agents do not work, it is optimal not to create inequity when only one agent works ($w_i^i - c_i = w_j^i$). Given that rewards cannot be negative (Assumption (R1)), the minimum rewards needed to be paid such that agent i prefers to individually work than not to work are $w_i^i = c_i$ and $w_j^i = 0$ and there is no inequity in equilibrium. For the game to have a unique equilibrium, rewards offered off-equilibrium, i.e., when both agents do work or when agent j individually works need to satisfy the inequalities given by ICC_j^{ind}, ICC_i^{indU} and ICC_j^{indU}. These can be satisfied for different combinations of the off-equilibrium rewards that do not affect rewards paid in equilibrium. The proof of *Proposition* 2.1 rewrites these conditions in a more compact form. Notice however, as an example, that if off-equilibrium all agents were offered no reward, i.e.,

$w_1 = w_2 = w_i^j = w_j^j = 0$, the game would not have a unique equilibrium, as no production would also be an equilibrium. For the equilibrium to be unique under the lowest reward cost for the principal, it is necessary that working is a dominant strategy for the agent who individually works in equilibrium (agent i) and thus, ICC_i^{indU} needs to hold. It is also necessary that the agent who does not work in equilibrium (agent j) prefers to individually work than not to work when the other agent does not work and thus, ICC_j^{indU} is also required.

2.4.2 Optimal contract to implement joint production with inequity averse agents

Define ICC_i^{JP} as agent i's incentive compatibility constraint for joint production to be an equilibrium of the game (not necessarily unique) and ICC_i^{JPU} as the constraints required for the equilibrium to be unique corresponding to agent $i = 1, 2$. The problem is the following:

-The principal maximizes its profit:

$$Max\ 1 - w_i - w_j$$

subject to:

- Assumptions (R1), (R2).
- (ICC_i^{JP}): $w_i - c_i - \alpha \max[w_j - c_j - w_i + c_i, 0] - \beta \max[w_i - c_i - w_j + c_j, 0] \geq w_i^j - \alpha \max[w_j^j - c_j - w_i^j] - \beta \max[w_i^j - w_j^j + c_j]$,

  for $i, j \in \{1, 2\}$ with $i \neq j$.

For the game to have a unique equilibrium with the lowest total reward cost paid by the principal, the following constraints are also necessary:

- Let the inequality in (ICC_i^{JP}) for agent i be strict, while for agent j be weak. Then:

  (ICC_i^{JPU}): $w_i^i - c_i - \alpha \max[w_j^i - w_i^i + c_i, 0] - \beta \max[w_i^i - c_i - w_j^i, 0] < 0$,

  (ICC_j^{JPU}): $w_j^j - c_j - \alpha \max[w_i^j - w_j^j + c_j, 0] - \beta \max[w_j^j - c_j - w_i^j, 0] > 0$.

We solve this problem in *Proposition* 2.4. But first, *Propositions* 2.2 and 2.3 state general results that describe the worst possible punishment for each agent when they do not work. By punishing agents when they do not work, agents' ICC_i^{JP}s are relaxed and rewards paid in equilibrium can be low. First we look at the reward offered to the agent who does not work that maximizes his punishment when the other agent individually works (w_i^j).

Proposition 2.2 *To generate the worst possible punishment to an agent who does not work when agents are inequity averse, it is optimal to offer zero rewards to the agent who does not work while the other agent individually works* ($w_i^j = 0$).

The intuition behind this result is that due to limited liability (R1), rewards offered cannot be negative, and due to (U2) agents care more for their direct utility than for the comparison with the other agent, thus the disutility of an agent shirking is maximized when he is offered no reward.

We now look at the reward offered to the agent who individually works off equilibrium that maximizes the punishment of the shirking agent.

Proposition 2.3 *To generate the worst possible punishment to an agent who does not work when agents are inequity averse, it is optimal to offer extreme rewards to the agent who individually works (agent i). If the potential effect of envy on the shirking agent (j) is relatively high ($\alpha(q_i - c_i) \geq \beta c_i$), agent i must be offered all the output he individually produces ($w_i^i = q_i$). If, in contrast, the potential effect of guilt is relatively high ($\alpha(q_i - c_i) < \beta c_i$), agent i must be offered no reward when he individually works* ($w_i^i = 0$).

Agent j derives disutility both from *envy* and *guilt,* but not from both at the same time. The punishment from *envy* is maximized when the other agent is offered all available output ($w_i^i = q_i$), and thus the maximum disutility generated by *envy* is equal to $\alpha(q_i - c_i)$. The punishment from *guilt* is maximized when the other agent is not offered any reward when he performs costly effort ($w_i^i = 0$). Thus the maximum disutility generated by *guilt* equals βc_i. Therefore, the relevant comparison is $\alpha(q_i - c_i) \gtreqless \beta c_i$. Thus, using *Propositions* 2.2 and 2.3 the *envious* agent j obtains minimum utility when he does not work and agent i works because not only he does not get any reward (by *Proposition* 2.2), but experiences the maximum feasible *envy* as agent i is paid the maximum available reward. On the other hand, the *guilty* agent j obtains minimum utility when he does not work because not only he is paid no reward but he also experiences the maximum feasible *guilt* because agent i is performing a costly effort and is paid the lowest feasible reward, which given (R1) is zero.

Notice that without budget constraints and limited liability, the potential to maximize the punishment from *envy* and *guilt* would be unlimited. The principal could threat an agent who does not work by offering the other agent an infinite reward when he individually works (to maximize *envy*) or offer an infinite monetary punishment (to maximize *guilt*). We assume (R1) and (R2) to restrict attention to limited and credible threats of inequity.

In the conditions that determine whether *envy* or *guilt* maximize the punishment to the shirking agent, not only do the inequity aversion parameters (α and β) enter, but also the costs of effort relatively to productivity. Thus, it is easy to reinterpret these conditions in terms of costs of effort. Intuitively, if the cost of effort of the agent individually working off the equilibrium is low ($c_i \longrightarrow 0$), the potential to punish the shirking agent due to *guilt* is low. Agent j does not feel very *guilty* when leaving agent i to work individually because working is not very costly for agent i. But, in contrast, agent j would feel very *envious* if agent i is offered a high reward when he individually works, as the net effect after subtracting the low cost of effort would be high. By rewarding individual work as high as possible (limited by the amount of total output produced) the principal maximizes the punishment from *envy*. In contrast, if working is relatively costly ($c_i \longrightarrow q_i$), the principal maximizes punishment from *guilt* by offering no reward to the agent who individually works.

We finally look at the optimal contract to implement joint production. The following *Proposition* 2.4 is the main result of this chapter and shows the optimal rewards for all output levels when joint production is implemented as the unique equilibrium of the game. *Proposition* 2.4 incorporates results from *Propositions* 2.2 and 2.3.

Proposition 2.4 *To implement joint production when agents are inequity averse, the optimal contract is as follows:*

1. An agent who does not work is offered no reward ($w_i^j = w_j^i = 0$).

2. Case a) If the maximum feasible punishment for both shirking agents is generated via envy, both agents are offered all available output when they individually work ($w_i^i = q_i$ and $w_j^j = q_j$).

Case b) If the maximum feasible punishment for one shirking agent (agent i) is generated via envy and for the other agent (agent j) is generated via guilt, then one agent is offered all available output when he individually works ($w_j^j = q_j$) while the other agent is offered no reward when he individually works ($w_i^i = 0$).

Case c) If the maximum feasible punishment for both shirking agents is generated via guilt, then one agent is offered all available output when he individually works ($w_j^j = q_j$) while the other agent is offered no reward when he individually works ($w_i^i = 0$). Which agent is offered all available output is determined by the relative maximum effect of guilt and envy for each agent.

3. Indifference between working and not working when the other agent works uniquely determines the rewards agents are paid in equilibrium (w_i and w_j).

The intuition for this result is as follows. First, following *Proposition* 2.2 an agent who does not work when the other agent individually works is offered no reward

($w_i^j = w_j^i = 0$). This minimizes agents' direct utility when they shirk, providing more incentives for them to work. Second, the utility of a shirking agent can be further minimized by creating inequity through the reward offered to the agent who individually works. Following *Proposition* 2.3 the shirking agent obtains minimum utility when the agent who individually works is offered extreme rewards, i.e., either all available output ($w_i^i = q_i$) or no output at all ($w_i^i = 0$). This is determined by whether $\alpha(q_i - c_i) \gtreqless \beta c_i$.

In cases *a)* and *b)* in *Proposition* 2.4, it is optimal to maximize the punishment to the shirking agent and thus, extreme rewards are offered to the agent who individually works. In case *c)* it is not optimal to maximize the punishment to the shirking agent as the equilibrium of the game played by the agents would not be unique. No production would be also be an equilibrium in which the utility of both agents would pareto dominate the utility when they both work and thus, the principal would not be certain that such contract would implement joint production when it is optimal to do so. The expression for the rewards paid in equilibrium in each of the three cases is shown in the proof of *Proposition* 2.4, although we here explain it graphically. Below we see the three cases in more detail.

Case *a)* shows the optimal rewards paid when it is optimal to exploit both agents' *envy* when they shirk ($w_i^i = q_i$ and $w_j^j = q_j$). Equilibrium wages are obtained by equating the utility of each agent when both agents work to the utility of each agent when they shirk given that the other agent individually works.[17] Indifference curves are drawn in Figure 2 below as combinations of w_i and w_j such that agents' utility when they both work is the same as when they shirk and the other agent works. The principal seeks to maximize profits and thus, chooses equilibrium wages such that both agents' prefer to work than not to work (which occurs in the shaded area in Figure 2) and such that the sum of equilibrium wages is the minimum possible. Given the slopes of the indifference curves defined by (U1) and (U2), this occurs at the unique point at which both agents' indifference curves intersect. Notice that whether this point is on either side of the 45^o line depends on which agent suffers more from inequity aversion when the other agent individually works (in this case, whether $q_j - c_j \gtreqless q_i - c_i$). Figures 2 and 3 show both cases. This has an immediate interpretation: the agent who suffers more from *envy* when shirking is the agent who obtains less direct utility in equilibrium.

[17] As it happened with standard agents, one of the agents receives a negligible extra reward of ε for the equilibrium to be unique.

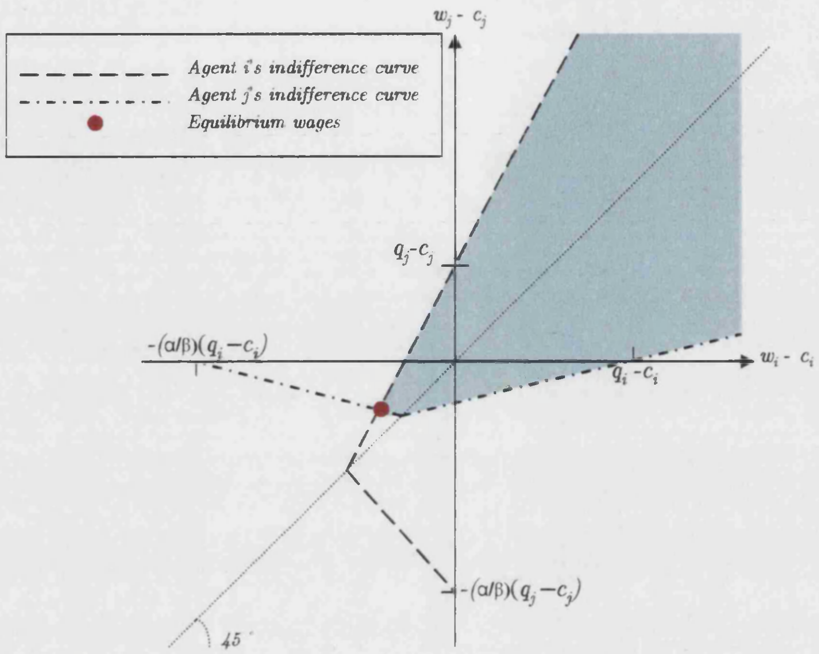


Figure 2: Equilibrium rewards when *envy* dominates for both agents and $q_j - c_j \geq q_i - c_i$.

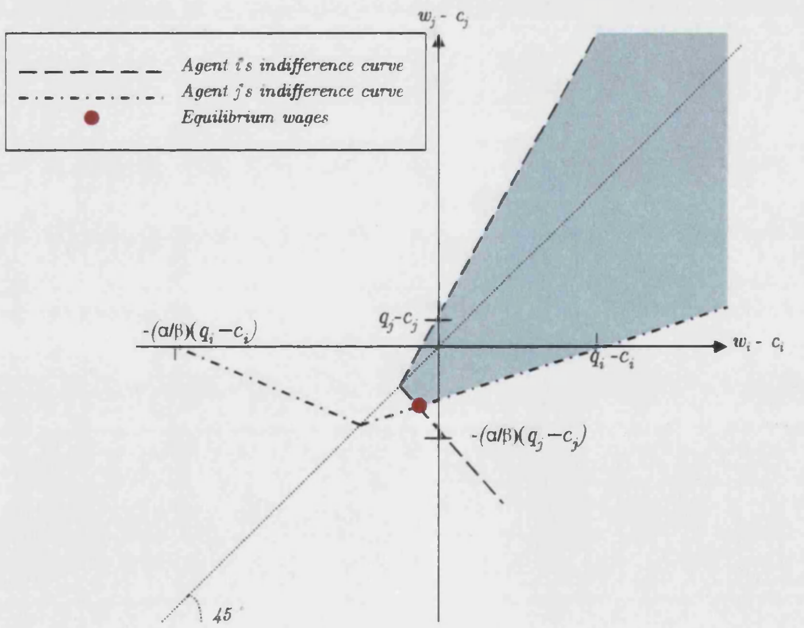


Figure 3: Equilibrium rewards when *envy* dominates for both agents and $q_j - c_j < q_i - c_i$.

Case *b)* shows the optimal rewards paid when it is optimal to exploit agent *i*'s *envy* and agent *j*'s *guilt*, and thus, it is optimal to offer all available output to agent *j* when he individually works ($w_j^j = q_j$) and no reward to agent i when he individually works ($w_i^i = 0$). Again, equilibrium wages are obtained at the intersection of both agents' indifference curves. Figure 4 shows the case were $\alpha(q_j - c_j) \geq \beta c_i$ and thus, agent i suffers more from *envy* when he individually shirks than agent j suffers from *guilt* when he individually shirks. Therefore, equilibrium wages are on the left hand side of the 45^o line implying that in equilibrium agent i obtains less direct utility than agent j. A symmetric graph can be drawn for the case $\alpha(q_j - c_j) < \beta c_i$.

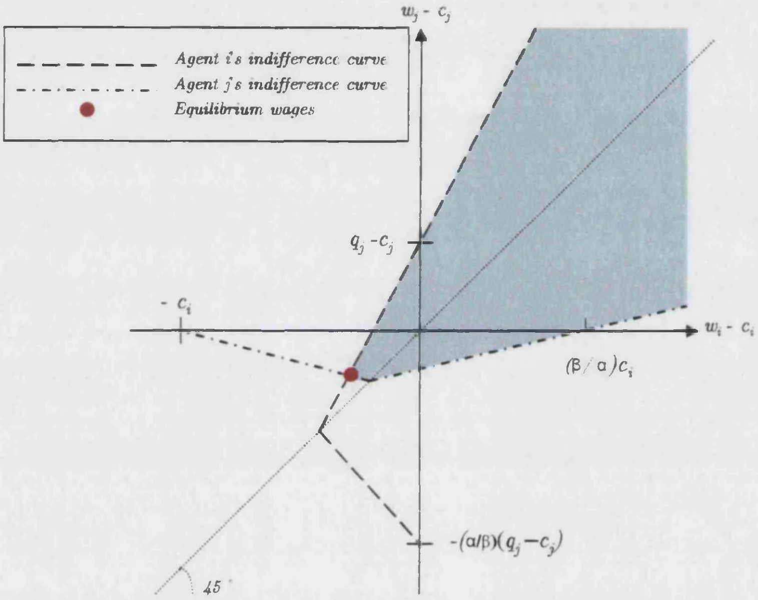


Figure 4: Equilibrium rewards when *envy* dominates for agent i, *guilt* dominates for agent j and $\alpha(q_j - c_j) > \beta c_i$.

Finally, we look at case *c)*. When $\alpha(q_i - c_i) < \beta c_i$ and $\alpha(q_j - c_j) < \beta c_j$, the maximum punishment from *guilt* on the shirking agent dominates the maximum punishment from *envy* for both agents. Thus, the punishment to the shirking agent is maximized via *guilt*, by offering both agents a reward equal to zero when they individually work ($w_i^i = w_j^j = 0$). However, notice that this would imply that both agents would prefer not to work when the other agent is also not working, turning no production into an equilibrium of the game played by the agents. Therefore, one of the rewards offered to an individually working agent has to be changed for the equilibrium to be unique under the lowest total reward cost for the principal. Notice that it is optimal to continue offering extreme rewards, in this case, no reward is offered to one of the agents when he individually works while all the available production is offered to the other agent when he individually works.[18] Thus, off equilibrium, one agent will feel the maximum possible effect of *envy* while the other will feel the maximum possible effect of *guilt*.

The choice of which agent is offered all the available output when he individually works depends on the difference between the maximum possible effect of exploiting each agent's *envy* and *guilt*. In particular, it is crucial to compare $\alpha(q_j - c_j) \gtreqless \beta c_i$ and $\alpha(q_i - c_i) \gtreqless \beta c_j$. The principal, in order to maximize profits, chooses off-equilibrium rewards such that the sum of the rewards paid in equilibrium is the lowest possible. Figures 5 and 6 below show the "optimal" indifference curves (drawn at the level of utility for which each agents' *guilt* is exploited off-equilibrium) and the "suboptimal" indifference curves (drawn at the level of utility for which each agents' *envy* is exploited off-equilibrium). Profits are maximized at one of the two intersections between an "optimal" indifference curve and a "suboptimal" one. This is determined by which of the two points is intersected by the lowest possible iso-profit function $(1 - w_i - w_j)$. In Figure 5, both points are on the same side of the 45^o line, meaning that no matter if agent i's *envy* or *guilt* is exploited off equilibrium, agent j obtains more direct utility in the unique equilibrium of the game than agent i. Figure 6, draws the case where depending on which agents' *envy* or *guilt* is exploited, one agent would be better off than the other in the equilibrium of the game played by the agents.

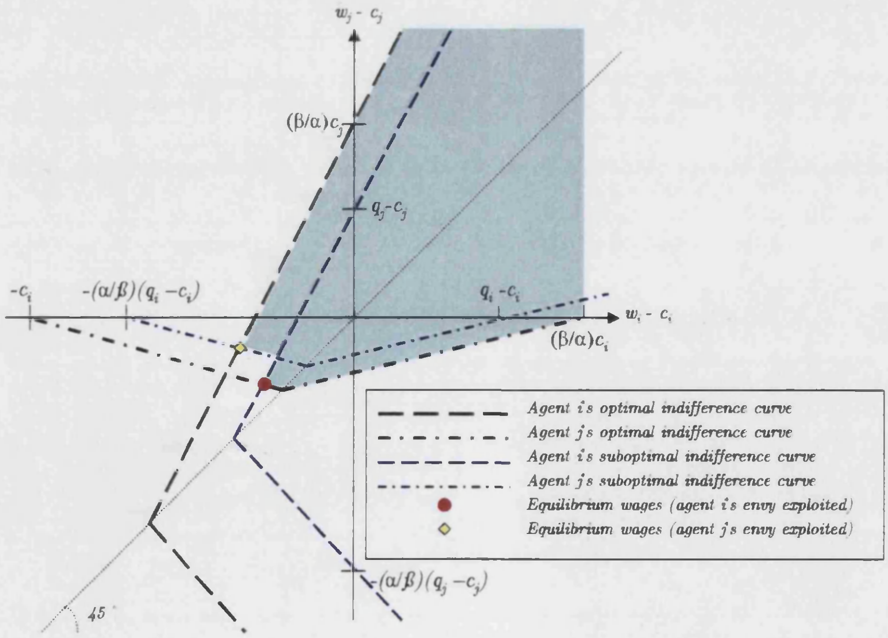


Figure 5: Equilibrium rewards when *guilt* dominates for both agents and agent j obtains higher direct utility.

[18] Notice that when maximum *guilt* cannot be generated due to the equilibrium not being unique, it is optimal to go to the other extreme and generate the maximum possible *envy*.

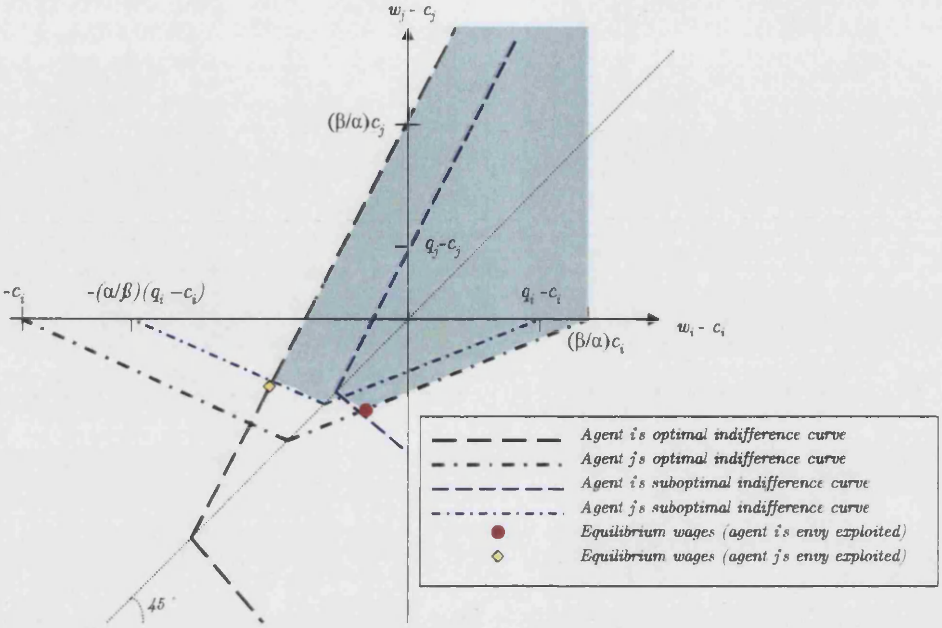


Figure 6: Equilibrium rewards when *guilt* dominates for both agents and it depends which agent obtains higher direct utility.

Finally, using the results of *Proposition* 2.4 we conclude the following:

Corollary 2.1 *The principal obtains higher profits when implementing joint production with inequity averse agents than with standard ones.*

Intuitively, the principal could always implement joint production by exactly compensating both agents for their cost of effort when they work, and offering them no reward when they do not work. The reason is that in equilibrium, when both agents are exactly compensated by their costs of effort, there is no inequity and thus, transformed utilities are the same as direct utilities. However, the principal can do better than exactly compensate the costs of effort, and thus, gain higher profits by paying a lower total sum of rewards. Following *Propositions* 2.2 to 2.4 , the principal can generate inequity off the equilibrium of the game such that inequity averse agents' utilities are lower than standard agents' direct utilities. Thus, by paying agents a reward smaller than their cost of effort but maintaining more equity in equilibrium than off-equilibrium, joint production is optimally implemented at a lower total cost for the principal than with standard preferences.

Notice that each agents' equilibrium rewards are not necessarily lower than in the standard case, but the sum of the two rewards paid is. This does not mean that equity is maximized when joint production is implemented nor that rewards paid in equilibrium are the same for both agents. Rewards paid just need to be sufficiently close for both ICC_i^{JP}s to hold at the lowest total reward cost in equilibrium for the principal.

2.4.3 Optimal production level with inequity averse agents

Once we have shown how the optimal contract is designed to implement each production level, we look at the conditions for each output level to be optimal. Notice that from previous results it is obvious that whenever the conditions for joint production to be optimal with standard agents are satisfied ($q_i < 1 - c_j$ for $i, j = 1, 2,\ i \neq j$) it is still optimal to implement joint production when agents are inequity averse. The reason is that while the total sum of rewards needed to be spent in equilibrium to implement individual production is the same with standard and inequity averse agents, from *Corollary* 2.1 the total sum needed to implement joint production is lower with inequity averse agents. Thus, it is possible that under same values for the productivity parameters, it may be optimal to implement individual production by standard agents while it may be optimal to implement joint production with inequity averse agents. Obviously, changes of equilibrium implemented from individual production by one agent to individual production by the other agent are not possible.

The proof of *Corollary* 2.1 shows the three possible rewards paid in equilibrium depending on conditions in *Proposition* 2.4. We here show the conditions for the principal to find optimal to implement joint production under the three possible sets of equilibrium rewards paid when agents are inequity averse:

- If $w_i = c_i - \dfrac{\alpha^2(q_i - c_i) - \alpha(\beta - 1)(q_j - c_j)}{\alpha + (1 - \beta)}$ and $w_j = c_j + \dfrac{\alpha\beta(q_j - c_j) - \alpha(1 + \alpha)(q_i - c_i)}{\alpha + (1 - \beta)}$,

then joint production is optimal when $q_i > 1 - c_j - \dfrac{\alpha(1 + 2\alpha)(q_i - c_i) + \alpha(1 - 2\beta)(q_j - c_j)}{\alpha + (1 - \beta)}$.

- If $w_i = c_i - \dfrac{\alpha\beta c_i + \alpha(1 - \beta)(q_j - c_j)}{\alpha + (1 - \beta)}$ and $w_j = c_j + \dfrac{\alpha\beta(q_j - c_j) - \beta(1 + \alpha)c_i}{\alpha + (1 - \beta)}$,

then joint production is optimal when $q_i > 1 - c_j + \dfrac{(1 + 2\alpha)\beta c_i + \alpha(1 - 2\beta)(q_j - c_j)}{\alpha + (1 - \beta)}$.

- If $w_i = c_i + \dfrac{\beta^2 c_i - \alpha(1 + \alpha)(q_j - c_j)}{\alpha + (1 - \beta)}$ and $w_j = c_j - \dfrac{\alpha^2(q_j - c_j) + \beta(1 - \beta)c_i}{\alpha + (1 - \beta)}$,

then joint production is optimal when $q_i > 1 - c_j + \dfrac{\alpha(1 + 2\alpha)(q_i - c_i) + \beta(1 - 2\beta)c_j}{\alpha + (1 - \beta)}$.

- Otherwise, the principal implements individual production by the agent for which $q_i - c_i$ is highest.

The Appendix contains a numerical example showing how the optimal contract changes when, under same productivity parameters, it is optimal to implement individual production with standard agents and joint production with inequity averse agents. The Appendix also contains a second example which shows that even if the optimal production level does not change, the loss in profits the principal incurs when he does not take into account inequity aversion is far from negligible. This example is symmetric as we assume $q_1 = q_2 = 0.5$ and $c_1 = c_2 = 0.4$. Under those parameter values it is optimal to implement joint production when agents are standard and thus, it is still optimal to implement joint production when agents are inequity averse. The loss for the principal is defined as the difference in its profits (production minus rewards paid) between offering a contract that accounts for inequity aversion and a standard contract to inequity averse agents as a proportion of the total joint production (normalized to 1). This loss is an increasing function in the *envy* (α) and *guilt* (β) parameters. In the example, the principal's loss can be up to 40% of the total output produced.

2.5 Status and Efficiency seeking Preferences

It can be argued that in some contexts, other types of distributional preferences might be more relevant than inequity aversion. In particular, in very competitive firms, agents might not dislike inequity but instead they might enjoy it, at least as long as it is the other agent who is worse off than them. Such agents will not feel *guilt* but *spite* when being better off than their peers, while they will still feel *envious* when being worse off. We call these agents "Status Seeking", interpreting having higher status as being higher in the ranking of agents' welfare, i.e., as being better off than other agents.

In other contexts in which each agent contributes a lot to total production, agents might feel disutility when shirking because the total amount of output, and thus, the total amount of rewards available to be distributed among agents, gets smaller when they shirk. We call these agents "Efficiency Seeking", interpreting efficiency as the sum of agents' welfare net of the costs of effort.[19]

These distributional concerns have been captured by other forms of utility functions.[20] However, it is worth noticing that by simply changing the range of values parameters α and β in the F&S utility function can take, it is possible to look at the array of possible purely distributional concerns in a unified model. We now use this

[19] In fact, Engelmann and Strobel (2004) find in a comparative test of distributional preferences that in the laboratory most data are better explained by efficiency concerns than by other distributional preferences such as inequity aversion.

[20] See Charness and Rabin (2002) for a summary.

re-parametrization of the F&S model to explore its consequences in optimal contract design. Notice that the problems we solve are the same as in Section 2.4, although solutions change when we allow for different parameter values.

2.5.1 Reward Design with Status Seeking Preferences

Assume now that $\alpha \in [0,1)$, $\beta < 0$ and $|\beta| \leq 1$. This means that agents are still averse to disadvantageous inequity but like advantageous inequity. The following two *propositions* cover the key issues of contract design when agents are status seeking.

Proposition 2.5 *To implement individual production when agents are status seeking, rewards paid in the equilibrium of the game are the same as with standard agents ($w_i^i = c_i$ and $w_j^i = 0$).*

As it happened with inequity averse agents, the optimal contract to implement individual production implies paying the agent who individually works (i) a reward exactly equal to his cost of effort (c_i) and paying no reward to the shirking agent. The reason is that in the right hand side (RHS) of ICC_i^{ind} there is no production and thus, both agents are paid zero and no agent is ahead. One could argue that since agent i likes being better off than his peer, it would be easier to provide incentives for agent i to work by making him better off than agent j when agent i individually works. However, given that it is still optimal to pay no reward to agent j when he does not work (due to (R1) the principal cannot pay him less), the only way to make agent i better off than agent j is by rewarding agent i above his cost of effort, which cannot be optimal. Thus, as it happened with inequity averse agents, status seeking preferences cannot be used to implement individual production with lower rewards than with standard preferences.

We now look at the optimal contract to implement joint production.

Proposition 2.6 *To implement joint production when agents are status seeking the sum of rewards paid in equilibrium is lower than with standard agents. The optimal contract is as follows:*

$$\begin{array}{ll} w_i = c_i - \frac{\alpha^2(q_i-c_i)-\alpha(\beta-1)(q_j-c_j)}{\alpha+(1-\beta)} < c_i & w_j = c_j + \frac{\alpha\beta(q_j-c_j)-\alpha(1+\alpha)(q_i-c_i)}{\alpha+(1-\beta)} < c_j, \\ w_i^i = q_i & w_j^i = 0, \\ w_i^j = 0 & w_j^j = q_j, \end{array}$$

for $i,j = 1,2, i \neq j$.

Notice that to implement joint production, the only way to use inequity off the equilibrium of the game is by generating disutility via *envy* on the agent who shirks, and thus it is optimal to offer no reward to the agent who shirks and all individual output to the agent who individually works. Therefore, only *envy* is used in this case. The reason is that *spite* provides utility to the shirking agent, making his ICC_i^{JP} more difficult to hold. Rewards paid in the equilibrium of the game are defined by case *a)* in the proof of *Proposition* 2.4. The graphical representation is the same as in Figures 2 and 3. Now things are even better for the principal. As agents like to be better off than each other, the reward paid in equilibrium to the agent who is best off is lower than with inequity aversion.[21] Notice that as in case *a)* in *Proposition* 2.4, the agent who suffers more from *envy* off-equilibrium is the one who will optimally be worse off in the equilibrium, i.e., if $q_j - c_j \geq q_i - ci$ then the optimal w_i and w_j are such that $w_j - c_j \geq w_i - c_i$. Finally, notice that with status seeking agents when joint production is implemented, both agents are paid in equilibrium a reward lower than their cost of effort.

Following results in section 2.4.3, the principal finds it optimal to implement joint production when $q_i > 1 - c_j + \frac{\alpha(1-2\beta)(q_j-c_j)+\alpha(1+2\alpha)(q_i-c_i)}{\beta-1-\alpha}$ for $i, j = 1, 2$, $i \neq j$. Otherwise, the principal implements individual production by the agent for which $q_i - c_i$ is highest.

2.5.2 Reward Design with Efficiency Seeking Preferences

Assume now that $\alpha < 0$, $\beta \in [0, 1/2)$, and $|\alpha| \leq |\beta|$. This implies that agents care for the weighted sum of direct utilities, putting more weight on each own's direct utility than on the other agent's direct utility. This leaves the possibility for the principal to exploit efficiency seeking preferences. The following two *Propositions* cover the key issues of contract design when agents are efficiency seeking.

Proposition 2.7 *To optimally implement individual production when agents are efficiency seeking, the sum of rewards paid in the equilibrium of the game is the same as with standard agents* ($w_i^i + w_j^i = c_i$)

Intuitively, the agent who individually works in equilibrium (agent i) must prefer to work than not to work given that agent j does not work. When both agents do not work rewards are zero and thus, agent i should obtain positive utility when working for his ICC_i^{ind} to hold. However, the only way to use that agent i is efficiency concerned to implement an equilibrium in which he individually works and paying a lower reward than his cost of effort is by offering "more efficient rewards". i.e., a total sum of rewards that adds up to more than agent i's cost of effort. This is a contradiction. Thus, individual production cannot be implemented with a total sum of rewards paid

[21] The expression is the same but, given the parameter values, it takes a lower value.

in equilibrium lower than the cost of effort of the agent who individually works. Notice that with efficiency seeking agents equilibrium rewards are not necessarily equal to the cost of effort of the agent who individually works, although the sum of rewards paid must be equal to it.

We now look at the optimal contract to implement joint production.

Proposition 2.8 *To optimally implement joint production when agents are efficiency seeking the sum of rewards paid in equilibrium is lower than with standard agents. The optimal contract is as follows:*

$$\begin{array}{ll} w_i = c_i + \frac{\beta^2}{\alpha+(1-\beta)}c_i > c_i & w_j = c_j - \frac{\beta(1-\beta)}{\alpha+(1-\beta)}c_i < c_j, \\ w_i^i = 0 & w_j^i = 0, \\ w_i^j = 0 & w_j^j = c_j, \end{array}$$

for $c_i > c_j$.

Notice that, contrary to previous sections, now extreme rewards (all production or no production at all) are not offered to all agents off the equilibrium of the game. In particular, agent j is offered a reward equal to his cost of effort when he individually works ($w_j^j = c_{j,}$). The reason is that offering the most inefficient rewards off equilibrium, i.e., no reward to all agents off equilibrium, the equilibrium of the game would not be unique. Notice that if $w_i^i = w_j^i = w_i^j = w_j^j = 0$, then no production is clearly an equilibrium of the game, as agents obtain the same rewards when they both do not work than when they individually work and there is more efficiency when they both do not work, as rewards are the same and equal to zero but no agent performs costly effort. To obtain uniqueness, it is necessary to offer a reward that compensates one agent for his cost of effort when he individually works, in order for him to prefer to work than not to work, given that the other agent is not working. The choice of which agent is offered a reward equal to his effort cost when individually working is determined by agents' costs of effort. Notice that *Proposition* 2.8 says that the agent who has a smaller cost of effort (agent j) is the one that must be offered a reward equal to his cost of effort when he works. The reason is that, by offering a reward equal to zero to the agent with highest cost ($w_i^i = 0$), the principal creates more inefficiency off-equilibrium and thus, he can implement joint production as the unique equilibrium of the game with the lowest possible total sum of rewards paid. Also notice that the agent with the highest cost is paid in equilibrium a reward higher than his cost of effort ($w_i = c_i + \frac{\beta^2}{1+\alpha-\beta}c_i > c_i$ as $\beta < \frac{1}{2}, |\alpha < \frac{1}{2}|$), while the other agent is paid a reward sufficiently lower than his cost of effort ($w_j = c_j - \frac{\beta(1-\beta)}{1+\alpha-\beta}c_i < c_j$), such that the total sum of rewards paid in equilibrium is lower than the sum of both agents' cost of effort ($w_i + w_j < c_i + c_j$).

Finally, it is optimal to implement joint production when agents are efficiency concerned whenever $1 - c_j + \frac{\beta(1-2\beta)}{1+\alpha-\beta}c_i > q_i$ and $1 - c_i + \frac{\beta(1-2\beta)}{1+\alpha-\beta}c_i > q_j$ for $c_i > c_j$. If these conditions are not satisfied, the principal implements individual production by the agent for which $q_i - c_i$ is highest.

2.6 Discussion

We have shown how distributional preferences change optimal contracts in a simple principal-agent setting where agents have already entered the firm. The sum of optimal rewards paid to implement joint production are lower than with standard agents and the optimal level of production can change. Therefore, the principal can exploit distributional preferences to obtain higher profits.

Notice that our results are collusive proof as the contract determines that the game played by the agents has a unique equilibrium. Equilibrium Uniqueness is important since exploiting distributional preferences to the principal's advantage implies that both agents would be worse off when they both work than when they do not. Thus, if the equilibrium was not unique, agents could coordinate on not working to avoid being exploited by the principal. Notice also that since agents care more for their own rewards than for equity, our results are also collusive proof to ex-post transfers among agents.

Despite its simplicity, our model provides a new rationale for team and relative performance contracts in contexts with no informational asymmetries. In both these types of contracts, agents are threatened with welfare inequities when some employees work harder than others. In team contracts, when a member of the team shirks, the team's performance is less successful and thus, other members of the team who work hard do not see their efforts rewarded, for which the shrinking agent might feel guilty. Therefore, agents might decide not to shirk even if rewards offered to them are low in order to avoid feeling guilty for the members of the team who work hard. In relative performance contracts, when an agent does not work hard he will be ranked low, and thus, he will be worse off than higher ranked agents, for which he may actually feel envious. Thus in competitive contexts it may not be necessary to offer such high rewards when agents are envious of each other and compete not to be ranked lower than their peers. Thus, welfare comparisons among peers can be used by the employer to provide incentives to work hard. Our results can be interpreted as showing when it is optimal to use team or relative performance contracts, depending on how employees compare to their peers.

Our model highlights that behavioural Contract Theory can be useful to study issues of organization in the firm. Both the Human Resources Literature and the

Personnel Economics Literature have studied these issues before.[22] The contribution of our study is that it indicates how those comparisons among agents can be affected by the design of the contract. Our model suggests that optimal contracts depend on the strength of welfare comparisons. If that is the case, it may be possible to affect the strength of those comparisons in the workplace. We have here assumed everything was given and common knowledge. However, in real firms the employer might be able to influence which information is easily available to his employees, once it has been clarified which variables enter employees' welfare comparisons in different contexts. In particular, decisions such as whether to make salaries publicly available to co-workers or not, or the allocation of office space (which might affect the observability of effort by co-workers) could be illuminated by issues here discussed. Although in many firms rewards are kept secret[23] and employees work in separate and closed offices, we have here provided a factor that in some cases may push towards the opposite direction.

[22] See Lazear (1995).

[23] Even if Bewley (1999) reports that 87% of managers interviewed think that their employees know each others' wages.

Chapter 3

Endogenous Leadership in Teams[1]

3.1 Introduction

In a recent experimental study Gächter and Renner (2003) illustrate the mechanics of "leading by example". In a team of agents one team member acts as leader by choosing his effort prior to all others. Gächter and Renner observe that the leader's effort influences the effort choice of all team members. The higher the leader's effort, the higher the effort of the other team members. Strikingly, this holds even though there are no monetary incentives that would induce such complementarities. Nevertheless, team members moving at the second stage follow the example set by their leader—which, in fact, reduces their monetary payoff.[2] Consequently, "bold" leadership, i.e., exerting high efforts as a first mover, can be beneficial, both for the leader and the team as a whole.

In this chapter we suggest a way of modeling such leadership mechanics and show how leadership can arise endogenously. Our model is driven by the assumption that some agents might dislike effort differentials. For obvious reasons we shall call such agents, who have a tendency to be influenced by their peers, "conformists". A tendency of agents to match efforts of their peers has been documented in various recent empirical studies. For example, Falk and Ichino (2003) document peer effects in a controlled field experiment and Bandiera, Barankay, and Rasul (2004) observe strong peer effects among fruit pickers.

In team production that we study here conformism turns out to be a two-edged sword. While it tends to reduce efforts of highly productive agents it tends to increase

[1] This chapter is joint work with Steffen Huck.

[2] Remarkably, Gächter and Renner make this observation even for one-shot games.

the efforts of less productive agents. Nevertheless, we can show that teams always benefit (weakly) from exogenously imposed or endogenously arising leadership. Material output and payoffs are higher in the presence of a leader.

Furthermore we show that endogenous leadership arises if and only if there is at least one team member who is a conformist and we analyze whose leadership is most desirable. Interestingly, it turns out that, everything else being equal, team output is maximized if the least productive agent takes on the role of team leader. Moreover, if agents vary in their degree of conformism, team output is maximized if a comparative non-conformist is leader.

Previous theoretical attempts to model leadership have invoked asymmetric information. In Hermalin's (1998) model leaders have private information about the team's productivity and, thus, can signal the team's productivity by their effort choice. While this is an extremely plausible model, it cannot explain Gächter and Renner's data where information is symmetric and, indeed, complete.

This note is organized as follows. In Section 3.2 we introduce two simple static models with two agents where the timing of agents' effort choices is exogenous. We show that sequential moves, i.e., having a leader always increases outputs as long as there is at least one conformist in the team. Furthermore, we demonstrate the main comparative statics results in this section. In Section 3.3 we allow for endogenous timing, following the modelling approach of Hamilton and Slutsky (1990). We show that, whenever at least one agent is a conformist, agents will indeed choose effort sequentially, increasing team output. Section 3.4 concludes.

3.2 Exogenous timing

Consider two agents $i = 1, 2$ who produce some joint output that they share equally. Each agent chooses some effort $x_i \geq 0$. For simplicity, let the output, y, be linear in efforts, i.e.,

$$y = 2(k_1 x_1 + k_2 x_2) \tag{3.1}$$

where $k_i \geq 0$ is agent i's constant productivity.[3] [4] Also for simplicity, we assume that the physical cost of exerting effort is quadratic such that agent i's *material* payoff is given by

$$\pi_i = \frac{y}{2} - \frac{1}{2}x_i^2. \tag{3.2}$$

Materially efficient production is therefore reached if agents choose $x_i^{EFF} = 2k_i$

[3] One might argue that team production is more likely to occur when efforts are complementary. However this complicates the algebra while our main qualitative results remain robust.

[4] Notice that in Gächter and Renner (2004) $k_1 = k_2$.

which, as we know from Holmström (1982) and will see in some detail below, they will not do with standard preferences. The efficient total output is $y^{EFF} = 4(k_1^2 + k_2^2)$.

In our model, an agent's utility depends on his material payoff and may depend on the difference between the agent's effort and the effort of his peer. More specifically, let

$$u_i = \pi_i - \frac{b_i}{2}(x_i - x_j)^2 \tag{3.3}$$

where $(x_i - x_j)^2$ measures effort differences and $b_i \geq 0$ measures agent i's degree of conformism.[6] Standard preferences are obtained as a special case of (3.3) for $b_i = 0$.

3.2.1 No leadership: Simultaneous moves

Now suppose that efforts are chosen simultaneously at some given point in time. Taking first-order conditions we can derive agent i's best-reply function as

$$x_i(x_j) = \frac{k_i + b_i x_j}{1 + b_i}. \tag{3.4}$$

It is easy to see that efforts are strategically independent only for $b_i = 0$, the standard case. However, with conformism efforts become *strategic complements.* Solving the two simultaneous equations we compute equilibrium efforts as

$$x_i^{SIM} = \frac{k_i(1 + b_j) + k_j b_i}{1 + b_i + b_j} \text{ for } i = 1, 2 \text{ and } i \neq j. \tag{3.5}$$

Analyzing the comparative statics we find that

$$\text{sign } \frac{dx_i^{SIM}}{db_i} = -\text{sign } \frac{dx_i^{SIM}}{db_j} = \text{sign } (k_j - k_i) \tag{3.6}$$

In words, the more productive agent's effort is decreasing in his own conformism and increasing in the other agent's conformism and vice versa for the less productive agent. The intuition for this result is simple. In order to reduce differences in efforts, agents adjust their effort choice towards the efforts of others. Thus, the more productive agent lowers his effort. And the more conformist he is the more he will lower it.

[6] In this environment, similar utility functions can be justified with other social preferences, for example, a variant of Fehr and Schmidt's (1999) inequity aversion. In their model agents receive a utility penalty that depends linearly on the difference between agents' material payoffs. Since $\pi_i - \pi_j = \frac{1}{2}(x_j^2 - x_i^2)$ and $(x_j - x_i)^2 = \left(\frac{x_j^2 - x_i^2}{x_i + x_j}\right)^2$ our "non-conformism penalty" can be obtained from their inequality penalty by normalizing with respect to total effort and taking the square. However, in more complex environments conformism and this form of inequity aversion do not necessarily coincide. Notice also that conformism, as we model it here, does not depend on symmetry. Agents care about choosing similar actions despite poetentially different productivities. In a richer model, the degree of conformism could also depend on how similar or different agents are. In the context of a principal-agent problem such an approach is taken, for example, by Hehenkamp and Kaarboe (2004).

On the other hand, the less productive agent increases his effort. Again the size of this adjustment is increasing in the degree of his conformism.

Total equilibrium output is easily calculated as

$$y^{SIM} = 2\frac{k_1^2(1+b_2)+k_2^2(1+b_1)+(b_1+b_2)k_1k_2}{1+b_1+b_2}. \tag{3.7}$$

Again we can take first derivatives in order to analyze the effect of conformism on output. It is easy to see (and, in fact, follows immediately already from (3.6)) that

$$\text{sign } \frac{dy^{SIM}}{db_i} = \text{sign } (k_j - k_i). \tag{3.8}$$

In words, total output is increasing in the less productive agent's conformism and decreasing in the more productive agent's conformism. Notice that any (moderate) increase in output implies increased material efficiency. If agents are equally productive, conformism has no effect on production in the simultaneous-move equilibrium.

3.2.2 Exogenous leadership: Sequential moves

Let us now assume that agents decide about their efforts sequentially, the second mover knowing the first mover's choice.[8] Notationwise, let agent 1 be the first mover and agent 2 the second mover. Solving by backwards induction it is obvious that agent 2 has to choose his effort according to (3.4), i.e., $x_2(x_1) = \frac{k_2+b_2x_1}{1+b_2}$. Anticipating this, the first agent maximizes

$$u_1 = k_1x_1 + k_2\frac{k_2+b_2x_1}{1+b_2} - \frac{1}{2}x_1^2 - \frac{b_1}{2}(x_1 - \frac{k_2+b_2x_1}{1+b_2})^2. \tag{3.9}$$

Solving the first-order condition we obtain

$$x_1^{SEQ} = \frac{k_1(1+b_2)^2 + k_2(b_1+b_2+b_2^2)}{(1+b_2)^2+b_1} \tag{3.10}$$

and, accordingly, along the equilibrium path

$$x_2^{SEQ} = \frac{k_2+b_2x_1^{SEQ}}{1+b_2}, \tag{3.11}$$

and

$$y^{SEQ} = 2(k_1x_1^{SEQ} + k_2x_2^{SEQ}). \tag{3.12}$$

[8] This does not necessarily require that agents work at totally separated times. Rather it might be that the first agent starts a little earlier than the second and that there is some inertia when efforts are exerted over time. In fact, when efforts are exerted over time there will always be an element of sequentiality as long as agents can observe what others are doing. Assuming two periods and a simple leader-follower structure is just a convenient way of capturing this.

We have seen above that under simultaneous moves with conformism, the more productive agent has an incentive to reduce his effort while the less productive agent has an incentive to increase his effort. Let us refer to this as the *pure conformity effect.* It still applies here. But with sequential play there is a second effect to which we refer as the *commitment effect.* Since efforts are strategic complements, the first mover knows that by increasing his effort he will also increase the effort of the second mover. This implies that his return on effort is greater than under simultaneous moves. This commitment effect is always positive. However, if the more productive agent moves first, his level of conformism must not be too great because otherwise the negative conformity effect can outweigh the positive commitment effect.

The relative sizes of the pure conformity and commitment effects are crucial for a comparison of output under simultaneous play and output under sequential play. The intuition we gained from above tells us that sequential play will be particularly good if the two effects are aligned, i.e., when the less productive agent moves first (because he will increase his effort due to both the conformity and the commitment effect). However, the actual comparison of outputs,

$$y^{SEQ} - y^{SIM} = b_2 \frac{(k_1 + k_1 b_2 + k_2 b_2)(b_1 k_1 + k_2 b_2 + k_2)}{(1 + 2b_2 + b_2^2 + b_1)(1 + b_1 + b_2)} \tag{3.13}$$

shows, since all parameters are positive, that the commitment effect *always* exceeds the conformity effect as long as the second mover shows a minimal tendency toward conformism.[10]

Examining (3.13) also reveals that, everything else being equal, it is always better for the team if the less productive agent moves first. For agents with equal (or similar productivity) it is, furthermore, better when the one who is more independent (that is, less conformist) moves first.[11]

Result 1 *Output with leadership always (weakly) exceeds output under simultaneous play. If the second mover is prone to conformism this holds strictly. Moreover, for agents equally prone to conformism, the less productive agent is preferable as leader. Finally, for equally productive agents, the agent who is less prone to conformism is the leader who maximizes output.*

[10] For equal productivities, $k_1 = k_2 = k$ (the case of Gächter and Renner, (2003)) this becomes $\frac{k^2 b_2 + 2k^2 b_2^2}{b_1 + 2b_2 + b_2^2 + 1}$. Hence, while there is no effect of conformism with equal productivities and simultaneous moves, our model does predict positive effects of leadership in a sequential-move game even if productivities are identical.

[11] The first claim can be easily established by substituting k_2 in (3.13) by $k_1 + \delta$ and then taking the first derivative w.r.t. δ. For the second claim one can simply normalize productivities to 1 and then evaluate (3.13) as $b_2 \frac{2b_2+1}{b_1+2b_2+b_2^2+1}$.

3.3 Endogenous timing

In the absence of a firm owner and principal who implements a leadership structure, it seems unclear how the agents themselves should decide about the order of moves and the issue arises whether agents are able to achieve the benefits of sequential play. Of course, they might be able to engage in some bargaining prior to choosing their efforts. But if they are able to reach binding agreements, the free rider problem should disappear in any case. Thus, we here outline what will happen in the probably more realistic and more interesting case when they cannot reach binding agreements.

A natural way to find an answer to this question is to model the agents' problem as a game with endogenous timing. Here we adapt Hamilton and Slutsky's (1990) framework which studies the emergence of Stackelberg leadership in (market) games. Let there be two periods, $t = 1, 2$. In the first period, agents either exert some effort or decide to wait. This happens simultaneously. In the second period agents who have decided to wait, learn what happened in $t = 1$ and then choose their effort. Applying backward induction, we find, similar to Hamilton and Slutsky, that there are three subgame perfect equilibria, one symmetric and two asymmetric ones. In the symmetric SPE, both agents choose x_i^{SIM} in $t = 1$. In the two asymmetric SPE, one of the agents chooses x_1^{SEQ} in $t = 1$ while the other waits and chooses x_2^{SEQ} in $t = 2$.[13] [14]

As Hamilton and Slutsky, we can deselect the first symmetric equilibrium because it is in weakly dominated strategies. Simply notice that if the other player chooses an effort in $t = 1$, an agent is always weakly better off by waiting since he can then play the best reply against this effort in $t = 2$. Moreover, if the other waits, waiting too is equally good as playing x_i^{SIM} in $t = 1$ as in both cases, both agents eventually choose x_i^{SIM}. Hence, waiting can never be worse than playing x_i^{SIM} in $t = 1$ and is sometimes better. Thus, we should expect one of the two asymmetric equilibria where agents move indeed sequentially.

We refrain from selecting a unique solution.[15] Instead we observe that, with endogenous timing, agents will always achieve (weakly) higher output than when forced to play simultaneously. (This follows immediately from the first part of Result 1 above.)

Result 2 *If the timing of effort choices is endogenous and at least one agent is a conformist, agents will choose their efforts sequentially which strictly increases*

[13] Off the equilibrium path, agents simply play best replies.

[14] To see that the latter are indeed equilibria notice that the agent who moves first picks his best point on the other agent's response function. Thus, x_1^{SEQ} is a best reply to the other's waiting strategy.

[15] For Hamilton and Slutsky's game, Van Damme and Hurkens (1999) provide a unique solution applying Harsanyi-Selten style equilibrium selection arguments.

material efficiency.

Notice that we assume that the leader-follower structure emerges because agents maximize utility and not their material payoff. However, as we see in Result 2 this will also increase their material payoffs. Thus, we see that, when timing is endogenous, teams with at least agent who is a conformist have a substantial advantage over teams where agents have standard preferences. In contrast to standard agents, agents with positive b's will benefit from the endogenously emerging leader-follower structure.

3.4 Incomplete information

So far, we have always assumed that both, agents' productivities as well as agents' degrees of conformism, are commonly known. This is obviously a heroic assumption and the question arises whether or not the results are robust if there is some incomplete information. Since, arguably, productivities are much easier to observe in the setting that we have in mind, the more pressing question is what would happen if agents have to face some uncertainty about their partners' degree of conformism. While a full-fledged analysis of this problem would go far beyond the scope of this chapter we did analyze the robustness of our results for the special case of equal productivities k (which is, in fact, the setup of Gächter and Renner, (2003)) and two possible values of b, zero and a strictly positive $\overline{b}$. The common prior attaches probability p to the latter type, and $1-p$ to the former (the standard type of economic theory).

With equal productivities we know that conformism has only bite if agents move sequentially and this, of course, remains true in the presence of incomplete information: both agents simply choose $x_i = k$ when they move simultaneously. With sequential moves the analysis becomes slightly more tedious but remains essentially straightforward. The analysis is greatly simplified through the observation that the type of the first mover is completely irrelevant for the second mover who only cares about the first mover's action. Hence, signalling is not an issue and there is a unique sequential equilibrium. (algebraic results are contained in the Appendix.) Also, for $p \to 1$ this equilibrium converges to the equilibrium of the game with complete information where $b_1 = b_2 = \overline{b}$. What is more, output under sequential moves again exceeds output under simultaneous moves, for all parameters.

The analysis of the game with incomplete information and endogenous timing is a little more elaborate but it turns out that the results we obtained above do again carry over. (See also the appendix.) In particular, there are sequentially rational equilibria with endogenous leadership. However, now there are two possible types of such equilibria—equilibria where, say, agent 1 moves first regardless of his b and agent 2 waits regardless of his b (or vice versa) and equilibria where the decision when to move is a function of b. It turns out that both types of equilibria coexist. First of all, the equilibria of the complete information case where leadership depends on the identity of agents are robust. In the game with incomplete information there are always asymmetric equilibria where, say, agent 1 moves first and agent 2 waits. In addition, there is also a symmetric equilibrium where high types with $b = \overline{b}$ move first and low types with $b = 0$ wait. Of course, in this equilibrium where the conformists become leaders and complete non-conformists followers, production is just as under simultaneous moves. Due to the insensitivity of the (endogenous) follower, there is neither a conformity nor a commitment effect. And the more desirable symmetric outcome where the non-conformist becomes the endogenous leader and the conformist the follower is, as it turns out, not an equilibrium. The reason for this is that a conformist has an incentive to deviate and move first since there is a chance that the other agent is a conformist, too, who can be stipulated to work harder *if* the deviating agent decides to lead by example.

The bottom line is that, in this simple model of incomplete information, endogenous leadership is predicted to arise but will only be beneficial for the team if agents coordinate on one of the asymmetric equilibria where the first agent leads regardless of his type.

3.5 Conclusion

In this chapter we have illustrated a model that captures the mechanics of "leading by example" documented in recent experiments (Gächter and Renner, (2003)). The model takes as its central assumptions one of the key results of Gächter and Renner's study, namely that agents exhibit a substantial degree of conformism, i.e., a tendency to reduce effort differentials even if this is costly for them. We show that with such conformism leadership is always beneficial for the team. Moreover, we show that leadership need not be imposed exogenously. When at least one agent is prone to conformism, leadership will, in fact, arise endogenously. Moreover, we show that, somewhat counterintuitive, teams should select the least productive agent as leader. This is because then the incentives induced through a pure conformity effect and a commitment effect are aligned. Finally, for equally productive agents, it is better for the team to have a "free spirit", i.e. somebody who is less prone to conformism, as leader.

Chapter 4

Equilibrium Play and Best Response to (Stated) Beliefs in Constant Sum Games

4.1 Introduction

A substantial portion of the experimental literature shows that game-theoretical predictions do not work well in the laboratory, even when the games played are very simple.[1] This is particularly true if subjects play games for the first time without previous experience. However, first time behaviour is crucial to model a vast number of economic situations which are not repeated, and it helps to understand what people bring into strategic settings. First time behaviour is also important to whatever learning occurs in repeated games. A natural question is to identify the class of games for which game theory predicts well when games are played for the first time and the reasons why it might fail in other games.

We aim to contribute to this question by looking at play and beliefs about opponents' play in simple but non-trivial games with similarities to others in which current experimental evidence shows that game theory predictions do not work so well. In particular, we study two-player 3x3 constant sum normal form games with unique equilibria in pure strategies and with different number of rounds of iterated deletion of (strictly) dominated strategies necessary to reach the Nash equilibrium. We obtain that in this class of games game theory predicts subjects' behaviour better than in previous experiments and we discuss the relation of our results with previous literature

[1] For example, see Güth, Schmittberger and Schwarze (1982), Camerer and Weigelt (1988), Och and Roth (1989), Cooper et al (1990), Brandts and Holt (1992). For an extensive survey, see Kagel and Roth (1995).

in which the theory predictions are not so successful.

For simple games with unique pure strategy equilibria, experimental evidence is not conclusive. While in 2x2 repeated games equilibrium play has found substantial support (McCabe et al. (1994), Mookherjee and Sopher (1994)), in games with more than two strategies for each subject and no possibility of learning equilibrium predictions start to fail. Stahl and Wilson (1995) found equilibrium compliance rates of 68% in 3x3 games with three rounds of dominance solvability. However, Broseta, Costa-Gomes and Crawford (2001) obtain in 2x3 games with three rounds of deletion of dominated strategies to reach equilibrium or with no dominated strategies equilibrium compliance rates ranging from 11% to 28%. For 4x4, 5x5 and 6x6 repeated games, the evidence is even more negative (Brown and Rosenthal (1990), Rapapport and Boebel (1992), Mookherjee and Sopher (1997)). Thus, choosing 3x3 games with different numbers of rounds of iterated deletion of dominated strategies may be a good starting point to disentangle the reasons why game theory loses its predictive power in games with more strategies available to players.

Our experiment is closely related to a previous experiment by Costa-Gomes and Weizsäcker (2004), who found low rates of compliance with equilibrium predictions, low frequency assigned to the belief that opponents would play equilibrium actions and low consistency between actions and belief statements, in the sense that the percentage of actions that were best responses to stated beliefs was low. Our results clearly differ from theirs, which may be caused by our games being constant sum and also to some procedural changes we made with respect to their experiment: payoffs were represented by single-digit numbers, there was no conversion rate between experimental currency and monetary payoffs, and the procedure to elicit beliefs was different. Below we explain why these changes may have made a difference.

First, as we have seen in chapters 2 and 3, one of the causes why game theory predictions may not work well in the laboratory may be that subjects have distributional and/or efficiency concerns. A possible reason for such concerns is that even if laboratory play may be completely anonymous, when games are played for the first time subjects may bring preconceptions on how to behave in strategic situations from previous real life experience that may cause divergences between equilibrium predictions and observed behaviour in experiments.[2] We choose to study constant sum games because, on a theoretical level, behaviour in them should not be affected by distributional and efficiency concerns. Efficiency concerns should not be an issue since subjects' payoffs always add up to the same amount, no matter which actions are chosen. Theoretically, distributional concerns should not affect behaviour as long as

[2] See Binmore (1998).

subjects care more for their own payoffs than for those of others.[3] This is because subjects with distributional concerns would have to give up the same units of payoffs that would go to their opponent in order to increase their opponents' payoffs. On the other hand, this theoretical result seems counter-intuitive.[4] In constant sum games all strategic behaviour refers to how to distribute a pie of a given size and thus, how fair the distribution is should matter to subjects with distributional concerns.[5] Of these preconceptions, a natural one is that, everything else equal, subjects should get equal shares.[6] Therefore, whether it is feasible to equally split payoffs or not, may have an influence on how subjects play constant sum games. We investigate whether distributional concerns influence subjects' choices in constant sum games and whether results are affected by equal splits being feasible. We find that subjects' behaviour is quite close to equilibrium and that it does not matter whether equal splits are feasible or not.[7]

A second issue related to games being played for the first time is whether subjects have formed meaningful beliefs about how their opponents will behave.[8] Although it is not necessary for subjects to hold beliefs about opponents' play for observed behaviour to coincide with equilibrium predictions,[9] it may help us to disentangle the reasons why subjects play or do not play according to game theory predictions in the laboratory. Therefore, we study if subjects are able to correctly predict their opponents' play and if their actions are consistent with their beliefs, in the sense that actions chosen are best replies to beliefs held. Experiments allow us to study this question by eliciting beliefs. We can distinguish between choice-based methods of eliciting beliefs (in which experiments are designed such that actions taken by subjects reveal information about beliefs)[10] and direct elicitation procedures (in which subjects are directly asked how

[3] Camerer et al. (1998).

[4] And in particular there is ample evidence that this result is not satified by Dictator Game data.

[5] There is at least one type of constant sum games where social preferences seem to affect how subjects play games: Dictator games. Becasue dictator games are sequential and more similar to the games in the following chapter, we discuss them further in Chapter 5.

[6] This has been observed in several experiments, for example in ultimatum games (Güth et al, (1982)).

[7] Previous research on contsant sum games has focused on whether subjects' frequencies of play in repeated constant sum games coincide with the probabilities with which subjects should play the one-shot mixed equilibria. Most results have been negative (Rapapport and Boebel (1992), McCabe et al. (1994), Mookherjee and Sopher (1997) and Walker and Wooders (2001)) although O'Neill (1987) and Binmore et al. (2001) are more positive. The discussion has focused on how data for mixed strategy equilibria should look like.

[8] Savage (1954) and Anscombe and Aumann (1963) define "beliefs" as subjective probabilities about uncertain events.

[9] And in particular, in constant sum games the Nash Equilibrium strategies coincide with Minimax and Maximin strategies, for which subjects only need to calculate their "safe" strategy, with no need to predict their opponents' strategy.

[10] See for example, Stahl and Wilson (1994), Nagel (1995), McKelvey and Palfrey (1995) or, more recently, Brañas and Morales (2003).

they think their opponents will play games).[11] We combine both methods and we actually check for consistency between actions chosen and beliefs stated.[12] Our results show that in fact subjects were reasonably accurate at predicting opponents' actions and that most choices were best responses to stated beliefs.

When beliefs are elicited directly, it is crucial to elicit them in a meaningful manner that subjects can understand. First, some authors, starting with Kahneman and Tversky (1973), express doubts on whether subjects can quantify their beliefs. Second, even if subjects may be able to quantify their beliefs, they might find some form of processing quantitative beliefs more meaningful than others. In this sense, following Gigerenzer (2000, 2002), we elicited beliefs by asking about frequencies of play by a pool of subjects instead of asking about probabilities of a single action chosen by a single opponent as it is frequently done.[13] This difference may be important when subjects only choose once in each game.

Having Elicited beliefs allows us to compare our results with previous research in which beliefs are used to study the degrees of complexity with which individuals are able to play games. We explicitly designed our games to be able to discriminate equilibrium behaviour from behaviour predicted by models varying in the degree of cognitive complexity that subjects are assumed to be able to process. Although depth of reasoning is a complex issue, these models approximate subjects' sophistication to whether they are able to best response to their beliefs about opponents' play and whether they form those beliefs anticipating that opponents may also behave strategically. Thus, they define the first degree of depth of reasoning as best responding to believing opponents choose their actions according to a uniform distribution and from them onwards higher degrees of depth are defined as best responding to the assumption that the opponent has the immediately lower degree of depth than one-self. In our games, we find that the equilibrium prediction clearly outperforms these models of depths of reasoning, both for the aggregate of subjects over all games and for a wide majority of individuals.

An alternative way to study cognitive complexity is to associate it with the number of rounds of iterated elimination of strictly dominated strategies subjects are able to perform. Thus, we designed our games such that they differed in the number of rounds of iterated elimination of dominated strategies that were necessary to reach the equilibrium outcome. We compare subjects' behaviour across games differing in the necessary number of rounds and we conclude that this was not a straightforward measure of how complex games were for subjects.

[11] See McKelvey and Page (1990), Offerman et al. (1996) and Nyarko and Schotter (2002).

[12] Costa-Gomes and Weizsäcker (2004) previously combined both methods of belief elicitation in normal form games.

[13] McKelvey and Page (1990), Offerman et al (1996), Costa-Gomes and Weizsäcker (2004).

The remainder of the chapter is organized as follows. Section 4.2 presents the experimental design and procedures. Section 4.3 contains the results and the main descriptive statistics. Section 4.4 concludes. The Appendices contain the instructions and we also show the games.

4.2 Experimental Design and Procedures

4.2.1 Experimental Design

Subjects were presented with a series of ten 3x3 Constant Sum Normal Form Games with Unique Equilibrium in Pure Strategies. For each of the ten games, they were asked to perform two tasks: they had to choose an action (between "UP", "MIDDLE" or "DOWN") and they had to report how many of the players on the other subjects' role they thought would play each of the three actions available ("LEFT", "CENTRE" and "RIGHT").

We constructed a 2x2 design according to two criteria. The first criterion was the order in which subjects had to perform the two tasks. In treatments BABAF and BABAU (to which we will generically refer as BABA treatments), subjects were asked for each game, first to state their Beliefs (B) and then to chose an Action (A), after which, they moved on to the next game. In treatments ABF and ABU (to which we will generically refer as AB treatments) subjects first chose an action in the ten games, without knowing what the second task would consist of, and then, after answers for all actions were collected, they were presented again with the ten same games and asked to state their beliefs about opponents' play. Comparing the BABA and AB treatments allows us to study whether eliciting beliefs before playing the games influences behaviour.

The second criterion was whether an equal split of payoffs was feasible in each of the games. As the games were constant sum, the sum of payoffs both subjects could earn was always the same and equal to £12, no matter the strategies chosen by both players. In treatments BABAF and ABF (to which we will generically refer as F treatments) an equal split of payoffs was feasible in one of the cells of all the games subjects played. Payoffs were designed such that both subjects would get £6 if they both took the strategy leading to this cell being chosen in each particular game. In treatments BABAU and ABU (to which we will generically refer as U treatments), payoffs in all games were substituted in this cell by a more unequal split, such that one subject would get a payoff of £7 and the other a payoff of £5. For example, in Game 4R below, payoffs when Row subjects chose MIDDLE and Columns subjects chose LEFT were £6 for both subjects in the F treatments, while they were £5 for

Row subjects and £7 for Column subjects in the U treatments. The location of the cell and the changes in payoffs from the F to the U treatments were designed such that it did not affect neither the predictions of the six behavioural models we study nor the degrees of strict dominance solvability, such that in some games it was the Row player who got a better than equal split of payoffs in the U treatments while in other games it was the Column player and such that subjects would get a higher payoff in this cell in some games (lower in other games) than in the Nash equilibrium outcome. Notice also that although the cell in which the equal split was feasible sometimes was in one of the subjects' equilibrium strategies it was never included in both subjects' equilibrium strategies, and therefore such cell never coincided with the Nash equilibrium outcome. Comparing the F and U treatments allows us to study whether the feasibility of an exact equal split influenced behaviour, which may be an indication of subjects' concerns for fairness in constant sum games.

Game 4R (U Treatment) Column

Row	Left	Centre	Right
Up	4, 8	2, 10	1, 11
Middle	5, 7	11, 1	4, 8
Down	7, 5	8, 4	10, 2

Game 4R (F Treatment) Column

Row	Left	Centre	Right
Up	4, 8	2, 10	1, 11
Middle	6, 6	11, 1	4, 8
Down	7, 5	8, 4	10, 2

4.2.2 Experimental Procedures

The experiment was carried out with pen and paper in the ELSE laboratory during April 2004. Subjects were recruited by e-mail using the ELSE database, which consists of UCL undergraduate and graduate students. As we are interested in behaviour played without previous experience, we only targeted subjects who had not participated in previous game experiments and whose field of study indicated that they would not be familiar with Game Theory and Economics.[14]

Our experiment consisted of four sessions with twenty subjects per session. In each session, ten subjects were randomly assigned "Row" roles in all ten games, while the

[14] Although we targeted unexperienced students, it turned out ex-post that 3 of our 80 subjects had taken introductory courses in Game Theory. However, neither their behavior in the experiment nor their explanations of their behavior in a post-experiment questionnaire were more "game theoretic" than their peers' so we did not exclude them from the sample.

other ten subjects were assigned "Column" roles. However, no subject was aware of their role (nor other subjects' roles) as games were presented to all players from the point of view of row players. Neutral language was used by calling subjects "You" and their opponents "Participants in the other group".

Upon arrival, subjects were randomly assigned seats and were asked to read some preliminary instructions, which described a strategic decision situation and the 3x3 payoff matrix associated with its normal form representation.[15] Then subjects were required to pass an Understanding Test where they had to demonstrate that they knew how to map players' actions in a game to outcomes, and outcomes to players' payoffs. Subjects were told that those who failed the test would act as "assistants" in the experiment. However, no subject failed the test in any treatment and so the over-recruited subjects were asked to assist the experimenter.[16]

The experiment consisted of ten games. In the BABA treatments subjects first read the instructions on stating first order beliefs and choosing actions and how they would be rewarded for these two tasks. Then subjects stated beliefs and chose actions for all ten games with no feedback. Subjects stated beliefs by writing down how many of the 10 subjects in the opponents' role they believed would chose each of their three possible actions in each game. In the AB treatments, subjects first read the instructions about how to choose their actions, and then played those games (Part I). After Part I, answer sheets were collected and subjects read the instructions on beliefs. Next, they stated their beliefs for all 10 games (Part II).[17] This procedure guaranteed that in the AB treatments, when subjects played the games, beliefs had not been mentioned. Finally, all answer sheets were collected. This procedure made sure that all subjects played all games before any feedback had been given. While payments were calculated subjects were asked to fill in an anonymous questionnaire, then subjects received their payments in private and left.[18] The Appendix reproduces the instructions for the BABA treatments.[19]

For each game subjects played they were randomly and anonymously paired with a different participant from the other group. Subjects never learned who their matched

[15] The strategic situations were called "Tables" in the instructions.

[16] All subjects were informed of this.

[17] Games were presented in random and different order to each subject to control for (possible) non-feedback learning. We varied the games and the order in which they were presented to prevent subjects from developing preconceptions about games' strategic structures and to help us discriminate between the different models of behavior we study.

[18] The purpose of the questionnaire was two-fold: it gave us time to calculate payments (with the help of an Excel sheet pre-programmed with the matching of subjects) and it provided information about subjects' fields of study, previous experience in experiments and comments on how they took their decisions.

[19] The text in the instructions for the AB treatments was practically the same. The only difference was in the order in which instructions were received.

participant in each game was, neither the action which was taken by their matched participant or any other participant in any game. Games were also presented in random and different order to all subjects. To ensure that subjects were motivated both to choose preferred actions and to state true beliefs, they were paid according to their answers in both tasks as follows. At the end of each session, a number from 1 to 10 was selected from a bingo urn. This number indicated for which of the 10 games all subjects would be paid for both tasks.[20] To reward actions, subjects were paid exactly the amount of pounds indicated by the number in the lower left corner of the cell chosen as a result of their action and the action chosen by their matched opponent in the particular game selected with the bingo urn.[21]

With respect to payments for stated beliefs, subjects were paid according to a Quadratic Scoring Rule (QSR) which rewarded accuracy between predicted frequencies of play of each action and the frequencies with which each of the three actions available were actually played by the 10 opponents in the game selected.[22] The QSR was designed such that subjects could earn comparatively less money with their belief statements than with their action choices (Maximum of £2 and £11 respectively). Had payoffs for both tasks been similar, risk averse subjects would have found incentives to take actions that were not best responses to their stated beliefs in the aim to average payoffs.

Subjects were paid the sum of a £5 fixed fee, plus their earnings for choosing actions and stating beliefs. Average payments were £12.78 (around $20 at the time). Each session lasted one hour and subjects were allocated forty minutes to perform both tasks in the ten games.[23]

[20] We paid subjects for one random game instead of for an aggregated measure of their answers in all 10 games to be able to maintain the one to one relationship between outcomes and payoffs. Avoiding conversion rates may help clarifying incentives, which may be particularly important in experiments in which beliefs on other subjects' behavior are elicited. As we discuss below, risk aversion did not seem to have been a problem.

[21] A British pound corresponded to 1.85 American dollars at the time of the experiment. Our design allowed us to provide reasonably high incentives while keeping one or two digit numbers to represent payoffs and avoiding conversion rates from experimental currency to monetary currency.

[22] Notice that when subjects are asked to predict the frequencies of play of a finite population of subjects, QSRs are not necessarily incentive compatible as subjects' average expectation of play of each action might not necessarily be equal to one of the possible empirical distributions over the finite set of opponents' actions. In any case, expected payoff maximizers can do no better by stating different beliefs than their true beliefs and given our results we think the problem is minor. For a discussion on QSRs see Offerman, Sonnemans and Schram (1996), Offerman and Sonnemans (2001) and Selten (1998). The particular QSR we used, along with an intuitive explanation for subjects highlighting that understanding the maths of the rule was not essential, can be found in the Instructions (Appendix A).

[23] In the AB treatments, 20 minutes were allocated for each of the two parts.

4.2.3 The Games

We classify our games according to whether they are dominance solvable or not. Eight of our games are dominance solvable. Of these, we classify them according to the number of consecutive rounds of iterated deletion of strictly dominated strategies needed to reach the unique Nash equilibrium. Games 1R and 1C are dominance solvable with one round of dominance to reach the equilibrium for one of the players (Row in 1R, Column in 1C) and two rounds of dominance for the other player. Games 2R and 2C are solvable with two rounds for one player (Row in 2R, Column in 2C) and three rounds for the other. Games 3R and 3C are solvable with three rounds of dominance for one player (Row in 3R, Column in 3C) and two for the other, although the first deletion of strictly dominated strategies is simultaneous for both players. Games 4R and 4C are solvable with four rounds for one player (Row in 4R, Column in 4C) and three rounds for the other. Finally, Games NR and NC are not dominance solvable and have no strictly dominated actions.[24] In the U treatments, Games 1R, 2R, 2C and 3R had additional weakly dominated strategies, apart from the strictly dominated ones.

We chose one-digit numbers to represent payoffs.[25] The sum of Row and Column players' payments in all cells of all games was 12.[26] The ten games were designed such that the equilibrium did not correspond to the same combination of actions by two players in more than two games.

We selected 3x3 games in which the prediction of how subjects would play would not be trivial. Accordingly, we designed the games such that we were able to discriminate Nash Equilibrium choices[27] from the choices predicted by five other models that have proven to be at least partially successful in previous studies on depths of reasoning.[28] These models are named L1, L2, L3, D1 and Maximax. L1 predicts that each subjects' action is a best response against the belief that the opponent is playing each action with equal probability. L2 predicts a best response against the belief that the opponent is playing according to L1 and L3 predicts a best response to the believing the opponent plays according to L2. D1 predicts a best response against a uniform

[24] Out of the six possible types of 3x3 constant sum games with unique pure strategy equilibria, we covered all but one possible case according to their degree of strict dominance solvability. The remaining case has a dominated strategy for one of the subjects and it is not dominance solvable.

[25] We did so because if subjects really chose their actions as a best response to their beliefs, calculating such best response in terms of expected payoffs may have been more difficult if numbers representing payoffs were large, and we did not want to discourage such type of behaviour.

[26] Numbers 10 and 11 were used in a few games to make it possible to discriminate models of behavior. Number 0 was not used to avoid behavior being possibly caused by aversion to getting no payoff.

[27] Simply referred as "Equilibrium", from here onwards.

[28] Stahl and Wilson (1994, 1995), McKelvey and Palfrey (1995), Broseta, Costa-Gomes and Crawford (2001), Costa-Gomes and Weizsäcker (2004), Weizsäcker (2003) and Goeree and Holt (2004).

belief over the opponents' undominated actions. Maximax predicts the action that is part of the action profile leading to the player's highest possible payoff in the game.[29] The Appendix contains the games, indicating the predictions of each of the six models, the round in which a dominated strategy is deleted and the payoffs that were changed to create the F and U treatments.

4.3 Experimental Results

4.3.1 Descriptive Statistics

Table 1 below presents the main descriptive statistics for each game when grouping all treatments and subject roles. We report, for each of the ten games, the percentage of equilibrium actions taken, the percentage of frequencies assigned to opponents' choosing equilibrium actions and the percentage of best responses to stated beliefs. A first look at results shows that roughly 80% of actions taken were according to equilibrium, that subjects believed the equilibrium action would be played with highest frequency (although with lower frequency than it was actually played), and that subjects actions were best responses to the distribution of stated beliefs in 73% of the cases. Frequencies were similar across games and the number of rounds of iterated dominance does not seem to affect percentages in a clear cut manner. However, notice that in the two games which are not dominance solvable (NR and NC) the equilibrium and best response frequencies show percentages that were lower than in the other games. This is particularly true for the percentage of best responses.

Game	Equilibrium Actions	Equilibrium Beliefs	Best Response to Stated Beliefs	N° Rounds Iterated Dominance (Row, Column)
1R	76.25	58.5	80	1,2
1C	75	59.375	75	2,1
2R	82.5	55.875	83.75	2,3
2C	81.25	51.125	71.25	3,2
3R	82.5	64.75	77.5	3,3
3C	86.25	63.125	77.5	3,3
4R	87.5	59.625	82.5	4,3
4C	78.75	59	80	3,4
NR	72.5	52.875	47.5	No
NC	73.75	51.5	55	No
Average	79.625	57.575	73	

Table 1: Descriptive statistics (percentages).

[29] Stahl and Wilson (1994) use a more sophisticated version of these models. According to their definition, L2 is a best response to a belief distribution which assigns positive weights to a portion of the population choosing actions randomly (L0) and the remaining portion to subjects best responding to uniform beliefs (L1). The reason to define the zero-level of rationality as an equal probability to play each possible strategy, and thus define degrees of rationality from there on, remains open.

The results of the informal questionnaire subjects answered after the experiment shows that a high percentage (95%) of the subjects who answered this questionnaire claimed to have taken their actions strategically, i.e., taking into account what their opponents would choose. Also, a high percentage of subjects (92%) claimed that they believed their matched participants would choose strategically, i.e., they would take into account the choice themselves made. Notice that in this questionnaire there were no monetary incentives for truth telling and that as subjects' answers were relatively vague, it was difficult to classify the level of strategic sophistication subjects claimed they had used from their answers. Therefore, in the following we use subjects' actual choices in the experiments and we compare the performance of different models that assume subjects' different level of strategic sophistication are able to predict subjects' choices and beliefs about how opponents would play.

4.3.2 Treatment Effects

In this section we study whether the different treatments in our design had an effect on subjects' choices or beliefs stated. In particular we study two questions: 1) whether eliciting beliefs immediately before actions had any effect on actions played or beliefs stated and 2) whether allowing for equal payoff splits changed behaviour.

We start with the first question. There are several reasons why we may think that belief elicitation prior to choosing actions can affect play. First, eliciting beliefs may make beliefs a more salient aspect of game play than they would otherwise. Second, asking subjects what they believe their opponents will do may cause subjects to predict the behaviour of their opponents more accurately than they otherwise would and thus, they may best respond more frequently to their stated beliefs. Third, when subjects are rewarded both for their stated beliefs and their actions, risk averse subjects could state their beliefs in a way that insures them against ex-post strategic mistakes (and vice-versa), so that strategy choices and belief statements could become mutually endogenous. Finally, rewarding beliefs subsidizes using beliefs to choose actions versus other procedures that might have been used when the rewards are not offered. Most of previous studies have found no effect of eliciting beliefs prior to actual play[30] although a recent article by Ruström and Wilcox (2004) reports some effects. We study this question by comparing the actions chosen and the beliefs stated in the BABA against the AB treatments.

First we look at actions chosen. We use Fisher's Exact Probability Test (FEPT) for count data[31] which tests if differences in observed proportions of actions chosen between two treatments might be expected by chance. The null hypothesis (two-tailed)

[30] See Nyarko and Schotter (2002) and Costa-Gomes and Weizsäcker (2003).

[31] Developed by Fisher (1935), Irwin (1935) and Yates (1934).

is that there is no difference in the probability of playing each strategy generating the observed proportion of play of each strategy in each treatment.[32] As with all statistical tests in this thesis, we used the free software R (2003) to perform FEPTs.

We conduct FEPTs separately for each game. We first compare subjects' aggregate actions for each player role (Row or Column) in each of the ten games between the BABA and the AB treatments (without aggregating the F and U treatments). Out of the 40 possible comparisons, we can never reject the null hypothesis that the underlying probability is the same at the 5% significance level.[33] [34] We then perform a stronger test by pooling the data for the F and U treatments[35] and again compare aggregate actions across players' roles between the BABA and the AB treatments. There is no p-value smaller than 5% so we cannot reject the hypothesis that there is no effect of the order of tasks performed in the aggregate actions.

Our next step is to test if the order of tasks affected subjects' belief statements. We collapse each agents' belief statements into one of four categories: for each of the three actions all the stated beliefs that assigned more than half of the frequency to an action were classified in the same category (thus creating three categories), and the last category comprises all the beliefs that do not assign more than half of the frequency to any of the three actions opponents can take. Again, this allows us to create a contingency table and use FEPTs to test for differences in belief statements between BABA and AB treatments.[36]

When comparing subjects' aggregate belief statements for each player role in each of the ten games between treatments BABA and AB treatments (without aggregating the F and U treatments) we cannot reject the null hypothesis of no difference in all comparisons. When we perform a stronger test by pooling the F and U treatments we can only reject it once (p-value equal to 0.003 for Row subjects in Game NC). Thus, we conclude the following:

Result 1 *The order in which subjects performed both tasks did not affect behaviour.*

[32] Although less common than the Chi-square test, Fisher's test requires less data in each category to be correctly calculated. Chi-square tests would require at least five subjects playing each action in each treatment which, given that most subjects chose the same actions, was not satisfied in our games. The main assumption required for both of these tests is independence between observations of the games in each treatment.

[33] Although FEPT is specifically designed for small samples it is still not a very powerful test with only ten observations in each treatment. For example using this test, we cannot reject that distribution of answers (3,2,5) in one treatment is the same as the distribution (1,7,2) in another treatment at the 5% significanc level. However, we can reject that it is different than (1,8,1). The power of the test increases with the number of observations.

[34] Qualitative results of all FEPTs in this section are the same at the 10% signicance level.

[35] This is allowed by results below.

[36] This procedure was previously used by Costa-Gomes and Weizsäcker (2004).

We now study whether the feasibility of equal payoff splits had an effect on behaviour. We proceed similarly as before by carrying out FEPTs for both actions and stated beliefs under the null hypothesis that there was no difference across treatments in the probability of playing (or stating) the observed proportions of play (or beliefs stated) of each action.

When comparing aggregate actions between the F and the U treatments for each player role (without aggregating the BABA and the AB treatments), no p-value is smaller than 5% out of 40 comparisons. When we pool the BABA and AB treatments and we compare the F and U treatments across player roles, only one out of the 20 possible p-values is smaller than 5% (p-value equal to 0.006 for Row subjects in Game 4C), which indicates that there is no significant effect. We also performed Mann-Whitney tests under the null hypothesis that the median of the distribution of games in which subjects chose the strategy containing the equal split was not different between the F and U treatments at the 5% significance level. Both when we aggregate the BABA and the AB treatments and when we do not, we could never reject the null hypothesis. Thus, we conclude that actions chosen were not affected by whether equal splits were available or not.[37]

Moving on to beliefs, we created a contingency table using the four categories mentioned before to classify beliefs stated and we performed FEPTs comparing same games under the F and U treatments to test for effects of equal splits on subjects' beliefs. We obtain no p-value smaller than 0.05 for the 40 comparisons when we do not aggregate treatments with respect to the order of tasks. When we do aggregate them, only one of the 20 possible p-values is smaller than 0.05 (p-value of 0.0189 for Column subjects in Game NC), which indicates that there is no effect of the feasibility of equal splits. We also performed Mann-Whitney tests comparing the distribution of average frequencies assigned to the strategy which contained the equal payoff splits between the F and U treatments, again for each game and player role. We could never reject the null hypothesis that the median of the distribution of frequencies assigned to the strategy containing the equal split was not different at the 5% significance level, both when aggregating the BABA and AB treatments and when not. Thus, we conclude the following:

Result 2: *Behaviour was not affected by the feasibility of equal splits.*

Small payoff differences between the equal and unequal split might explain Result 2. It would be worthwhile to study robustness to higher payoff differences. An alternative

[37] Same results were obtained for the null hypothesis that the feasibility of equal splits did not affect the median of the distribution of the number of games in which subjects played the equilibrium action neither of the number of games in which they best responded to their stated beliefs.

explanation is that the equal split was feasible (or not) in *all* the games subjects played. As subjects were only paid for one of the games, our experiment resembles the strategy method, in which a weakening of the "equal split effect" has previously been observed (Güth et al. (2001)). In any case, and admitting these caveats, our results show that there are circumstances in which subjects do not change their behaviour whether equal splits are feasible or not when deciding how to share pies of given sizes.

Given that we have obtained that the different treatments did not have an effect on subjects' choices or beliefs stated, we use results 1 and 2 to pool the data across treatments. For the remainder of the analysis we will report statistics on pooled data, although we will refer to the different treatments when required.

4.3.3 Actions

In this section we study subjects' actions and their compliance with dominance, iterated dominance and equilibrium predictions.

Subjects almost never played strictly dominated strategies. Each subject could have played a strictly dominated strategy in five of the ten games He/She played. However only 21 out of the 800 actions taken were strictly dominated (2.65% of the total actions chosen and 5.25% out of the possible dominated actions). Dominated actions were taken in only a few games and for specific player roles: 8 dominated actions were taken by Row subjects in Game 1R, 4 by Column subjects in Game 1C, 6 by Column subjects in Game 3R and 3 by Column subjects in Game 4C. Only one subject (Column subject 1 in treatment BABAF) chose more than one dominated strategy across the ten games played (she chose dominated strategies in Game 1C and in Game 3R).

Now we look at dominant strategies. Only Games 1R and 1C had a dominant strategy for one of the players (DOWN for Row subjects in 1R, RIGHT for Column subjects in 1C). Out of the 80 subjects who had a dominant strategy in one of these games, 68 (85%) chose the dominant strategy. The 12 subjects who did not choose the dominant strategy all chose the same strategy across player roles (MIDDLE for Row in 1R, LEFT for Column in 1C) which accounts for 57% of the total of dominated actions chosen over all games. Although the action chosen by these 12 subjects coincided in all cases with the one that had the equal split cell in the F treatments, this action was actually chosen more times in U treatments than in F treatments (seven times against five). Also notice that LEFT in Game 1C, was not only strictly dominated by the dominant strategy (RIGHT), but also by the other dominated strategy (CENTRE). Row subjects' dominated choices may have been explained by a desire to have certainty over own payoffs, as when choosing the dominated action, Row subjects would obtain the same payoff no matter what their opponents' choices were. Column subjects' dominated actions are more difficult to explain.

We now look at whether the number of rounds of iterated deletion of dominated strategies in each game affected the percentage of actions according to equilibrium taken. Table 2 shows the percentage of compliance with equilibrium predictions for each game by subject role.

Game	Row Subjects	Column Subjects	All Subjects	N° Rounds Iterated Dominance (Row, Column)
1R	80	72.5	76.25	1, 2
1C	60	90	75	2, 1
2R	95	70	82.5	2, 3
2C	75	87.5	81.25	3, 2
3R	92.5	72.5	82.5	3, 3
3C	87.5	87.5	86.25	3, 3
4R	87.5	87.5	87.5	4, 3
4C	67.5	90	78.75	3, 4
NR	92.5	52.5	72.5	No
NC	72.5	75	73.75	No
Average	81	78.5	79.625	

Table 2: Percentage of equilibrium actions by game and subject role.

On average, subjects played equilibrium actions in 79.625% of the cases. Notice that there is no clear pattern between the number of rounds of iterated deletion of dominated strategies required to reach the equilibrium and the percentage of equilibrium actions played. For example, games 1R and 1C show a lower percentage of equilibrium actions than games 3C or 4R. We also noticed that the lowest percentage of equilibrium play occurred in the non-dominance solvable games (NR and NC). We created contingency tables with the number of subjects who played equilibrium actions in each of the games (aggregating both subject roles) and performed McNemar's tests[38] under the null hypothesis that there was no statistically significant difference in the proportion of compliance with equilibrium between each pair of games. We do not find statistically significant differences between games at the 5% level, when we group both subject roles.[39] When we do not, some differences are significant, for example between Row subjects in game 2R and NC, but no clear pattern emerges.

[38]In the following, we use McNemar's to exploit the statistical power derived from having the same subjects playing across different games. When this is not fulfilled, we use Chi-square tests.

[39]This creates seven categories: subjects who reach the equilibrium strategy in 1 round of iterated deletion, 2 rounds, 2 rounds with simultaneous deletion in the first round, 3 rounds, 3 rounds with simultaneous deletion in the first round, 4 rounds and non dominance solvable. Notice that not all these categories have the same number of subjects, but that the Chi-square test allows us to do this comparison.

Thus the degree of iterated dominance needed to reach equilibrium is not a straightforward measure of the proportion of equilibrium play and thus, this may indicate that if subjects really reasoned in game theoretic terms, deleting more rounds to reach the unique equilibrium is not a good indicator of how complex these games were for subjects.

Overall we conclude:

> Result 3: *Subjects almost never played strictly dominated strategies and played equilibrium strategies in 80% of the cases. The number of rounds of necessary deletion of strictly dominated strategies to reach the Nash equilibrium was not a clear indicator of the percentage with which the equilibrium strategies were played.*

We now compare how well the equilibrium model predicted actions taken in comparison to other models. Table 3 shows the percentage of actions taken that were predicted by the standard equilibrium model, together with the percentage rates predicted by each the other five models described in section 4.2.3.

Game	Equilibrium	L1	L2	L3	D1	Maximax
1R	76.25	51.25	76.25	76.25	76.25	51.25
1C	75	62.5	75	75	75	47.5
2R	82.5	17.5	62.5	82.5	62.5	17.5
2C	81.25	56.25	81.25	81.25	56.25	16.25
3R	82.5	38.75	82.5	82.5	82.5	38.75
3C	86.25	48.75	51.25	86.25	86.25	13.75
4R	87.5	50	87.5	87.5	87.5	12.5
4C	78.75	61.25	78.75	78.75	61.25	17.5
NR	72.5	66.25	22.5	62.5	66.25	21.25
NC	73.75	50	46.25	11.25	50	15
Average	79.625	50.25	66.37	66.75	70.375	25.125

Table 3: Percentage of equilibrium actions predicted by each model.

Equilibrium outperforms the predictions of the other models in all games.[40] Although the games were intentionally constructed to highlight differences between models' predictions, it is noticeable that the two models that have been most successful in previous research on depths of reasoning perform clearly worse across all games than the standard equilibrium (L1 predicts 50.25% of the actions, while L2 predicts

[40] Equilibrium also outperforms each of the other models in all games when subject roles are not pooled.

66.375%).[41] Of the models analyzed, the one that comes second in predicting the aggregate of actions is D1, with a percentage of 70.375%. D1 predicts the same action as Equilibrium for five of the ten games. In the five games were the predictions of both models are different, Equilibrium outperforms D1 in all games, with an overall success rate of 77.75% against 49.35%.

Notice however, that L1 has strong predictive value for non Equilibrium actions. The action that coincided with the L1 prediction was the one which was chosen with at least second highest frequency in all 10 games for both subject roles. Additionally, out of the 163 actions that were not taken according to Equilibrium, 98 (60.12%) were taken according to L1. As a reference, only 43 (26.38%) of the non Equilibrium actions taken coincided with L2, with lower percentages for the other models. Thus, most subjects when they did not choose the Equilibrium action, they chose the action that gave them the highest expected payoff against a uniform distribution of play by their opponent (L1). This gives some support to L1 as a decision model when subjects do not know what to choose and do not have any particular beliefs on how their opponents will choose.

We now look at individual behaviour. First, table 4 shows the cumulative distribution function (CDF) of the percentage of subjects who played at least a certain number of games according to each models' predictions. We observe that while 20% of the subjects played according to the Equilibrium prediction in all ten games, at most only 1.25% of the subjects played in all ten games according to any of the other models here studied. Also notice that 70% of the subjects chose at least 8 actions according to the Equilibrium model.

N° Predictions	Equilibrium	L1	L2	L3	D1	Maximax
10	20	1.25	1.25	0	1.25	0
9	43.75	3.75	2.5	3.75	16.25	0
8	70	10	27.5	31.25	37.5	1.25
7	81.25	16.25	61.25	55	70	3.75
6	87.5	36.25	78.75	76.25	85	6.25
5	96.25	65	87.5	91.25	95	8.75
4	98.75	87.5	93.75	98.75	98.75	15
3	98.75	95	98.75	100	100	28.75
2	100	100	100	100	100	43.75
1	100	100	100	100	100	75
0	100	100	100	100	100	100

Table 4: CDF Of the percentage of subjects who play at least a number of times according to models' predictions.

[41] Notice that L2 predicts the same outcome as Equilibrium in six games, while L1 does not predict the same outcome as Equilibrium in any game. Thus, we should not infer that L2 captures behavior better than L1. L3 coincides with Equilibrium in all but Games NR and NC, where it performs significanty worse.

Second, we classified subjects according to the model whose predicted action subjects chose in the highest number of games. Table 5 shows the percentage of subjects who could be classified according to each model category. First, there were 56 out of the 80 subjects that could be clearly classified to a model according to this criterium. i.e., who responded the highest number of times according to only one model. Of these, 69.6% of subjects were classified as "Equilibrium". There are 24 subjects who could not be classified in this manner, as there were ties between various models. This is the reason why the sum of percentages of columns "Ties" and "Overall" adds up to more than a hundred percent. In any case, 87.5% of the subjects who tied between two models, chose the highest number of actions according to "Equilibrium" and some other model, while only 50% did it according to "L1" and another model. In the column "Overall", we add up both the clear cases and the ties to conclude that 75% of the 80 subjects can be classified as "Equilibrium", while only 26.25% of subjects can be classified as D1. Other models show lower percentages. Finally, we show in parenthesis the average number of games in which subjects classified in each model category chose actions according to each model. Notice that this average measures the intensity with which subjects were classified with respect to each model and thus, it shows that subjects classified in each category were quite consistent with the model in which they were classified.[42]

Classification	Clear Cases	Ties	Overall
Equilibrium	69.6 (9.05)	87.5 (7.86)	75 (8.63)
L1	5.36 (9.33)	8.33 (6.5)	6.25 (8.2)
L2	5.36 (8.66)	41.66 (7.2)	16.25 (7.53)
L3	1.78 (9)	25 (7.33)	8.75 (7.33)
D1	16.07 (8.66)	50 (8.08)	26.25 (8.34)
Maximax	1.78 (8)	8.33 (6.5)	3.75 (7)

Table 5: Classification in models to which subjects respond most times.

Thus, we conclude:

Result 4: *Equilibrium captures actions played by subjects better than the alternative models, both at the individual and aggregate levels.*

Although we cannot discard that there may be other models that capture behaviour better than those studied here or that, as we have seen, a small percentage of players'

[42] Had subjects chosen actions randomly they would have answered on average in 3.3 games according to each model and, given the structure of the games, the average intensity of subjects classified in each category would have been 5.1.

behaviour might be better captured by one of the other models presented here, it is clear that Equilibrium is a good predictor of actions taken for the particular class of games we study in this experiment.

Below we check if subjects also believed that their opponents would play according to Equilibrium.

4.3.4 Stated Beliefs

In this section we study subjects' stated beliefs about opponents' frequencies of play. We study whether subjects expected their opponents to play dominated strategies, whether they expected them to comply with the equilibrium prediction and we also check the accuracy of the frequency predictions with respect to the frequency of actions chosen.

Subjects believed their opponents would play dominated actions with higher frequency than they actually did. Over all games, subjects assigned 6.575% of frequency to dominated actions (13.15% of the possible frequency that could be assigned in the five games with dominated actions for each role subject) while dominated actions were played in 2.625% of the cases (5.25%).

On average, subjects expected their opponents to play the Equilibrium action with the highest frequency in each game, although the frequency with which Equilibrium was played was higher than the frequency with which subjects believed it was going to be played. We will refer to these as "conservative beliefs", following Huck and Weizsäcker (2001).

Overall, subjects assigned on average 57.6% of frequency to their opponents playing the equilibrium action. Frequencies assigned to equilibrium play were disperse. The lowest average frequency assigned to equilibrium play is 35.2% by Row subjects in Game 1R to Column players' action. The highest, 81.7% by Column subjects in the same game. Notice that Row subjects have a dominant strategy in this game, so these results indicated that most Column subjects did expect Row subjects to play the dominant strategy, while Row subjects where uncertain of how Column subjects would choose, as Column subjects did not have dominated strategies. Results in game 1C extend this intuition, although percentages are less clear cut.

Table 6 shows the average frequency assigned to Equilibrium actions by game and subject role. We do not observe any straightforward pattern between the number of rounds of iterated elimination of dominated strategies required to solve for the Equilibrium and the frequency of beliefs of Equilibrium play stated. However, it is still the case that when aggregating subject roles, in games NR and NC the frequency assigned to equilibrium actions is lower than in most of the other games (although not lower than in 2C). Performing Wilcoxon tests under the null hypothesis that there are no differences in the median of the distribution of frequencies of beliefs assigned to equilibrium actions between pairs of games, we obtain statistically significant differences at the 5% level between on the one hand games 1C, 1R, 3R, 3C, 4R and 4C and on the other games 2C, NC and NC.[43] When we performed Wilcoxon tests for each player role, we obtained several statistically significant differences, although there was not a clear pattern between the number of rounds of iterated dominance and the frequency assigned to equilibrium actions by opponents.

Game	Row Subjects	Column Subjects	All Subjects	N° Rounds Iterated Dominance (Row, Column)
1R	35.25	81.75	58.5	1, 2
1C	68.75	50	59.375	2, 1
2R	45.25	66.5	55.875	2, 3
2C	57.25	45	51.125	3, 2
3R	63.25	66.25	64.75	3, 3
3C	53	73.25	63.125	3, 3
4R	53	66.25	59.625	4, 3
4C	67.75	50.25	59	3, 4
NR	45.5	60.25	52.875	No
NC	49.5	53.5	51.5	No
Average	53.8	61.3	57.575	

Table 6: Average frequency assigned to equilibrium actions.

We now look at how the Equilibrium model for beliefs performs in the aggregate with respect to the other five models we are considering. Table 7 shows the frequency assigned to the predictions of the six models for each of the games. We observe a clear pattern: although in all the games the highest frequency was assigned according to the Equilibrium model (but in the already mentioned Game 1R where the L1 model performs slightly better), the percentage of predictions captured by each model are much closer when we look at belief statements than when we look at actions. In particular, contrary to what happens with actions, the average percentage of frequencies matched with Equilibrium model predictions (57.6%) and the average percentage matched with the D1 model predictions (55.4%) are very close. Notice also that the order in which each of the models is successful is practically the same with beliefs stated as it happened with actions (although with beliefs L3 outperforms L2).

[43] The distribution of the median of game 2R was also statistically different than the distribution of the median of games 3R and 3C.

Game	Equilibrium	L1	L2	L3	D1	Maximax
1R	58.50	61.25	58.50	58.50	58.50	61.25
1C	59.38	51.38.	59.38	59.38	59.38	42.38
2R	55.88	33.00	56.13	55.88	56.13	33.00
2C	51.13	49.75	51.13	51.13	49.75	36.63
3R	64.75	44.38	64.75	64.75	64.75	44.38
3C	63.13	49.75	36.75	63.13	63.13	23.38
4R	59.63	49.63	59.63	59.63	59.63	30.63
4C	59.00	54.25	59.00	59.00	54.25	31.25
NR	52.88	49.00	29.63	19.13	49.00	28.00
NC	51.50	39.88	40.75	22.13	39.88	26.38
Average	**57. 58**	**48. 23**	**51. 56**	**51. 26**	**55. 44**	**35. 73**

Table 7: Frequencies stated matched by models' predictions.

We thus conclude:

Result 5: *While Equilibrium still captures belief statements better than the other models studied here, differences with other models are smaller than with actions.*

The lower predictive value of the Equilibrium model and the small differences between the predictive value of competing models in belief statements seems to be caused by a tendency to conservatism in belief statements already observed in previous experiments (Huck and Weizsäcker (2001), Costa-Gomes and Weizsäcker (2004)). This tendency is also reflected in the low percentage of belief statements that assigned frequency one to all ten opponents playing one particular strategy (11.125%). However, tendency to conservatism does not mean that subjects assigned equal frequency to their opponents playing each of their three available actions. The percentage of uniform belief statements[44] is only 5.875%, much lower, in fact, than the percentage of belief statements that assigned zero frequency to at least one of the opponents' actions (42%). Costa-Gomes and Weizsäcker (2004) argue that the higher percentage of zero-belief statements than uniform beliefs is a reason to discard the hypothesis that the tendency to conservative beliefs might be caused by risk aversion. They argue that since QSRs punish large mispredictions, risk averse subjects would avoid losses by making roughly uniform belief statements, which subjects did not make in most of the cases. However, notice that even a highly risk averse subject would state zero beliefs to two of his opponents' actions if he was sufficiently certain about the actions that all opponents would take in a particular game. The reason for conservatism seems to be different. Given the high percentage of Equilibrium actions played, and the lower expectations

[44] Defined as statements that assigned frequency of 3 to two actions and 4 to the other one.

of opponents playing Equilibrium, it seems that subjects genuinely believed that their opponents would play Equilibrium less frequently than they did.

We now study the accuracy of belief statements by comparing stated frequencies with the frequencies with which each action was actually played in each game. As belief statements were conservative we should not expect them to be very precise. Before looking at precision we assess accuracy of belief statements in the aggregate by looking at whether subjects predicted the "structure of frequencies" correctly. We define correct structure of beliefs as subjects assigning highest frequency to the actions which were played with highest frequency and assigning lowest average frequency to the actions which were played with lowest frequency. Table 8 compares, for each game and subject role, the average frequency with which each of the three actions was played by subjects, with the average percentage of stated frequency assigned by the opponents to those same actions. It is noticeable that for all but three comparisons, aggregate average beliefs get the "structure of frequencies" played correctly.[45]

Game	Row Actions			Column Beliefs		
	UP action	MIDDLE action	DOWN action	UP Belief	MIDDLE Belief	DOWN Belief
Game 1R	0	20	80	3	15.25	81.75
Game 1C	5	35	60	16	34	50
Game 2R	95	5	0	66.5	20.25	13.25
Game 2C	25	0	75	42.25	12.75	45
Game 3R	92.5	2.5	5	66.25	8.25	25.5
Game 3C	0	85	15	6.25	73.25	20.5
Game 4R	0	12.5	87.5	5.5	28.25	66.25
Game 4C	67.5	32.5	0	50.25	40.75	9
Game NR	2.5	92.5	5	18.25	60.25	21.5
Game NC	2.5	72.5	25	16.25	53.5	30.25
	Column Actions			Row Beliefs		
Game 1R	22.5	5	72.5	40.75	24	35.25*
Game 1C	2.5	7.5	90	11.5	19.75	68.75
Game 2R	30	0	70	45.75	9	45.25*
Game 2C	5	87.5	7.5	11.75	57.25	31
Game 3R	15	72.5	12.5	27.25	63.25	9.5
Game 3C	0	12.5	87.5	20.25	26.25	53
Game 4R	87.5	0	12.5	53	14	33
Game 4C	90	2.5	7.5	67.75	21.75	10.5**
Game NR	7.5	52.5	40	16.75	45.5	37.75
Game NC	5	20	75	22.5	28	49.5

Table 8: Comparison of the percentage with which actions were played with percentages of belief frequencies assigned.

[45] The difference between frequencies assigned in those three games was, however, very small. These games are indicated in Table 7 with a star (*). The double star (**) in game 4C indicates that the order of beliefs with which the second and the third actions were played was inverted.

However, when looking at each subject individually, we observe that the patterns of aggregate behaviour do not translate well into individual behaviour across games. Table 9 shows the cumulative distribution function of the percentage of subjects who assigned the highest frequency to the correct action, as well as the lowest frequency at least in a number of games. It also reports the percentage of subjects who predicted the correct and the opposite structure of frequencies of actions in at least a number of games. Table 9 shows that subjects were good at assigning highest frequency to the actions which was played with highest frequency, but they were not so good in ranking the two other actions.

Number of Games	Highest Frequency	Lowest Frequency	Same Structure	Opposite Structure
10	10	0	0	0
9	25	1.25	0	0
8	36.25	5	1.25	1.25
7	50	15	5	2.5
6	75	31.25	8.75	3.75
5	87.5	53.75	18.75	6.25
4	92.5	70	35	12.5
3	95	88.75	50	23.75
2	96.25	98.75	76.25	32.5
1	100	100	90	71.25
0	100	100	100	100

Table 9: CDF of the percentage of subjects who predicted the structure of actions by their oponents at least in a number of games.

While 75% of the subjects assigned highest frequency in six or more games to the action that was played with highest frequency, only 8.75% of the subjects did, at the same time, assigned the lowest frequency to the action that was played with lowest frequency in those six or more games, and thus, answered with the same structure of frequencies of beliefs as their opponents played. Very few subjects assigned the ranking of frequencies in the opposite order as they were played by their opponents (32.5% of the subjects made this mistake two or more times). Also, 28.25% of belief statements assigned the same frequency to the two actions that were not believed to be played with highest frequency.[46] Figure 1 shows the scatter plot for each game of the frequency of stated beliefs for each action against the frequency with which those actions were played. The tendency is clearly increasing, supporting the evidence that, on average, subjects assigned higher frequency to actions that were played with higher frequency.

[46] These cases do not qualify for either the "Same structure" or the "Opposite structure" categories.

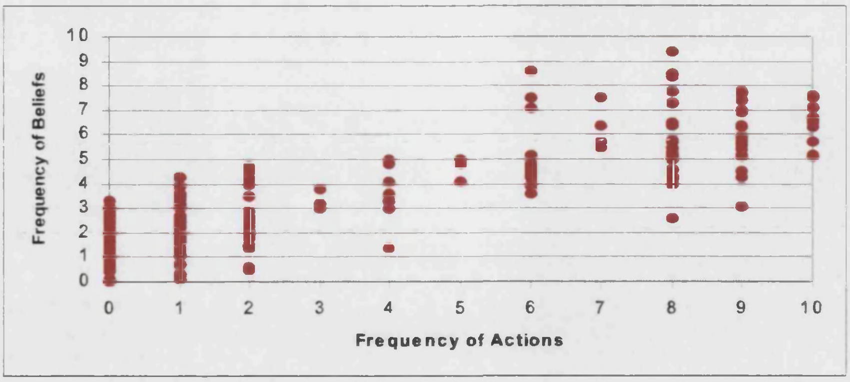


Figure 1: Average Frequency of Actions and Average Frequency assigned.

Finally, we look at the precision of belief statements. The average mean square error for the predictions of Row subjects about the frequencies of play of Column subjects was 2.49, while for Column subjects was 2.16. Random belief statements would have generated average mean square errors of 3.3 for Row Subjects and 4.1 for Column Subjects. We will use the average mean square errors in the next section to associate accuracy of predictions and best response behaviour. We conclude:

Result 6: *Subjects were good at predicting the actions that were played with highest frequency by their opponents, although stated beliefs tended to be "conservative".*

4.3.5 Best Response of Actions to Stated Beliefs

We finally look at the consistency of stated beliefs and actions at the individual level. We check for consistency by checking whether actions chosen by each subject were best replies to the same subject's stated beliefs (BR). We define best replying behaviour as choosing the action that gives the highest expected payoff given the distribution of beliefs stated. According to this definition, best replying implies that subjects' utilities only depend on own monetary payoffs and that subjects are risk neutral. Results below show that a majority of subjects satisfied this definition. Given that subjects were better at identifying the action which was played with highest frequency than the frequencies of the other two actions, we also check whether actions taken were a best response only to the action assigned the highest frequency (BR Max F).[47]

First, as it would be obvious from previous results, subjects clearly best responded to their stated beliefs more often than they would have had they chosen their actions randomly. Kolmogorov-Smirnoff Goodness of Fit Tests comparing the empirical CDFs

[47] As there are only three actions available for each subject and only ten units of frequency to be assigned, in many cases both models of best response behavior predict the same action.

to the CDF implied by random behaviour gives p-values of virtually zero. Table 10 shows the percentage of best responses by game and player role. Overall, subjects best responded to their stated beliefs in 73.375% of the cases (75.625% for best response to the highest frequency belief). This percentage is much higher than the observed in the only other study with elicited beliefs we are aware of on one-shot behaviour in a similar setting (Costa-Gomes and Weizsäcker (2004) with 50% of best responses). Furthermore, even if in our experiment there is no chance for learning, the percentage of best response behaviour is as high as the one observed in experiments that allowed for learning (Nyarko and Schotter (2002), with 75% of best responses in their 2x2 games).

Thus, we conclude:

> Result 7: *Subjects best responded to their stated beliefs a high number of times (73% of the cases).*

By comparing the percentage of best responses across games for all subjects using McNemar's test (5% significance level), we again observe the familiar pattern that the number of rounds of iterated dominance does not seem to affect in a clear way the percentage of best replies. However, it is true that the percentage of best responses was significantly lower in the two non-dominance solvable games (NR and NC) than in some of the other games. Both models of best response (BR and BR Max F) perform similarly, which may be due to stated beliefs not being too extreme.

	Row Subjects		Colum Subjects		All Subjects	
Game	BR	BR Max F	BR	BR Max F	BR	BR Max F
1R	80	80	77.5	75	78.75	77.5
1C	60	57.5	90	90	75	73.75
2R	90	92.5	77.5	75	83.75	83.75
2C	80	72.5	80	80	80	76.25
3R	80	90	72.5	72.5	76.25	81.25
3C	77.5	65	80	87.5	78.75	76.25
4R	82.5	82.5	85	75	83.75	78.75
4C	57.5	57.5	87.5	87.5	72.5	72.5
NR	60	52.5	40	80	50	66.25
NC	60	75	50	65	55	70
Average	72.75	72.5	74	78.75	73.375	75.625

BR: Best Response. BR Max F: Best Reponse to the action assigned highest frequency

Table 10: Average percentage of best responses.

Looking at the individual level, Figure 2 draws the empirical probability density function (PDF) of the number of games for which each subject best responded to their stated beliefs, overall and for each player role. Although only 3.75% of subjects best responded to their stated beliefs in all ten games. 70% of subjects best responded to their stated beliefs in seven or more games.

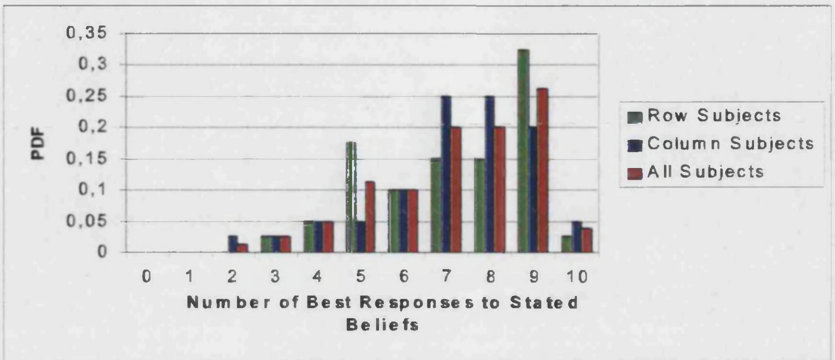


Figure 2: Empirical PDF of the number of times subjects best responded to their stated beliefs.

Although the proportion of non-best response behaviour is not insignificant, it is small. We look into the nature of non-best response behaviour by calculating how much subjects lost for not best responding to their stated beliefs. We use the monetary losses subjects made when non-best responding to their stated beliefs as a proxy for how important it was for subjects to best respond in each of the games.

We proceed by calculating, for each subject, the sum of his expected loss when not best responding to their stated beliefs averaged over the ten games each subject played. We find that Row subjects lost on average £0.3037 per game and Column subjects lost on average £0.3205 per game. Given that subjects were only paid for their actions in one game, these were the average losses per subject. Next, we calculate the average maximum feasible loss had subjects have played, in all games, the action that gave them the lowest possible expected payoff, given their stated beliefs. On average, Row subjects could have lost £3.05 per game while Column Subjects could have lost £2.69 per game. Finally, we divide both numbers to calculate for each subject in each game, the percentage of the maximum loss they incurred by not best responding. Averaging over all games for each subject role we obtain that Row subjects lost on average 10.97% of the maximum losses they could have made, while Column subjects lost 15.96% of the maximum possible losses. To put things in perspective, Row subjects would have lost 40.21% of the maximum possible losses they could have made had they chosen the action that neither was a best response nor the worst response to their stated beliefs in all ten games. Column subjects would have lost 55.24% of the maximum possible losses had their chosen this action in all 10 games. Therefore, we conclude:

Result 8: *As subjects best responded in most of the games, they did not lose much with respect to the maximum losses they could have made.*

Table 11 shows the percentage of average losses in each game for each subject role. Notice that these calculated losses are only hypothetical, as we obtain them using stated beliefs, not the actual matching of subjects in each game.[48] Differences between average losses for Row and Column subjects were probably caused by a variety of factors, including the beliefs stated but also the design of the games, which created higher payoff differences for Column subjects than for Row subjects.

Game	Row Subjects	Column Subjects
1R	9.56	14.61
1C	22.16	5.49
2R	8.73	3.74
2C	5.17	13.99
3R	6.12	21.60
3C	12.01	13.86
4R	6.72	10.33
4C	6.11	7.79
NR	16.81	46.64
NC	16.32	21.52
Average	**10.97**	**15.96**

Table 11: Percentage of average loss per game and subject role.

Not best responding is not the only kind of mistake subjects could have made. Subjects could also err in the accuracy of their predictions of opponents' play. Although the monetary loss derived from this mistake would be minimal, as payments for stated beliefs have an upper bound of £2, a bad prediction of how opponents play, even if it was a best response to stated beliefs, could result in taking a non-optimal action, given the frequencies with which opponents really played. We address whether both types of mistakes (bad predictions and non-best response behaviour) are related, by calculating the correlation between each subjects' average mean square error of his predictions and the average percentage of maximum loss for not best responding each subject makes. We find that there is positive significant correlation between both series (Pearson's coefficient of 0.559 with a p-value of 6.8e-08).[49] This high correlation means that subjects who chose equilibrium actions, also expected a high proportion

[48] An alternative way of calculating the hypothetical loses is to use the real frequencies of play by the opponents instead of the stated beliefs. Given that the percentage of best response to stated beliefs is similar to the percentage of best response to "real" play by the opponents, overall percentages by game differ only slightly.

[49] We also calculated the correlation between each subject's number of best responses with the mean square error of predictions and Pearson's coefficient was, as expected, negative and significant (Pearson's coefficient: 0.55, p-value 8.6e-08).

of their opponents to choose equilibrium actions, and that this prediction was right. This suggests that subjects may have believed that their opponents would choose their actions in a similar way as they did. We thus conclude:

Result 9: *Subjects who are better at predicting the frequencies of play of their opponents are also the ones who lost, on average, less for not best responding.*

Figure 3 draws the correlation between average losses and errors of predictions.

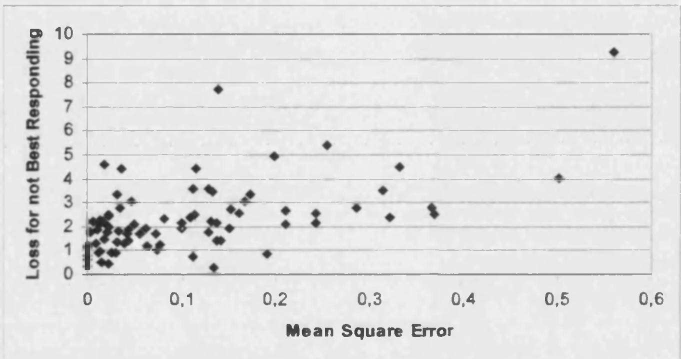


Figure 3: Correlation Between Average Losses for Not Best Responding and Mean Squared Errors of Predictions

4.4 Discussion

We have identified a class of non-trivial games for which game-theoretical predictions work reasonably well, even when games are played for the first time by subjects with no previous experience in laboratory games or knowledge of game theory. These games are constant sum games with unique equilibria in pure strategies. Our results imply that most subjects not only played according to the Equilibrium prediction but that they were reasonably good at predicting the actions that would be played with highest frequency by their opponents and they best responded to their beliefs on opponents play.

When surveying the experimental evidence in dominance solvable games, Camerer (2003, Chapter 5), claims that the joint hypothesis of game theoretic behaviour and social preferences that value only one's own payments is easily rejected. He then claims that the interesting question is whether the rejection is due to the pure self-interest part of the joint hypothesis or to the game theoretic reasoning part or even to both. We have here designed a simple experiment in which by using a theoretically useful control for social preferences, we check if subjects play according to the game theoretic prediction, and thus, this may indicate whether subjects are able to reason in game theoretic terms. Notice that this procedure does not allow us to answer whether individuals have social preferences or not, but only helps us to identify a class of games in which whether they have social preferences or not, the equilibrium prediction is reasonably accurate. Therefore, for our simple but non trivial games, the game theoretic part of the hypothesis is not rejected in a context in which we would not expect social preference to influence behaviour.

The number of rounds of iterated deletion of strictly dominated strategies to reach the equilibrium is not a straightforward measure of how complex games are for subjects and thus we can not conclude that in games with more rounds of deletion, the percentage of equilibrium played was lower. Whether games are dominance solvable or not seems to have an effect on the predictive power of game theory over these games, specially for the percentage of best responses. However, notice that in those two games at least one of the subjects could obtain the same payoff by choosing some particular strategy no matter the action chosen by their matched opponent. This, together with the impossibility of deleting dominated strategies, may have caused that subjects were worse able to predict how their opponents would play and, as a consequence, the percentage of equilibrium actions may have been lower in these games. We aim to conduct further research on non dominance solvable games in which this unfortunate characteristic is not present.

In any case, constant sum games seem like a good starting point to study how subjects reason in simple games as issues like fairness and efficiency concerns seem not to affect their choices. Equal splits neither influenced actions chosen nor beliefs stated about others' behaviour, although this point requires further investigation as the payoff differences between equal and unequal splits were low in our experiment. Belief elicitation does not affect how subjects play games and how they think other subjects will play them, although comparing our results to previous experiments, the different belief elicitation procedure we used may be important.

Our results may have been influenced by procedural changes with respect to previous experiments and in particular, to Costa-Gomes and Weizsäcker (2004). Apart from focusing on constant sum games, we used one-digit numbers to represent payoffs and there was no conversion rates between experimental payoffs and final monetary payoffs. The procedure for eliciting beliefs may be also of some importance when studying best response to stated beliefs. Given our results, it would be interesting to study how each of these changes affect results. It would also be interesting to estimate a model with noise, as they did, in which to jointly check the consistency between subjects' actions and the beliefs they have about their opponents. However, our results already hint that whether games are constant sum or not and some of the procedural changes we made make a difference in the predictive value of game theory. It seems wrong to generally dismiss Nash equilibrium as a good predictor of behaviour in simple games even if they are played for the first time by subjects with no particular training in Economics. Once we have this evidence, further research should aim to identify reasons for differences with previous evidence and ultimately, identify a possibly larger set of games for which game theory predictions work well.

Chapter 5

Equilibrium Play and Best Response in Sequential Constant Sum Games

5.1 Introduction

In the previous chapter, we identified a class of non-trivial games for which Nash Equilibrium predictions work much better than in similar previous research.[1] This occurred even if the games were played in the laboratory for the first time by non-Economics trained subjects with no feedback. These games were two-player 3x3 constant sum normal form games with unique equilibria in pure strategies and with different number of rounds of iterated deletion of (strictly) dominated strategies necessary to reach the Nash equilibrium. We here study how well the subgame perfect equilibrium prediction works in sequential games which share the same payoff matrix as the normal form games of the previous chapter and that were played again by Non-Economics trained subjects for the first time without previous experience in the laboratory. We check if the subgame perfect equilibrium prediction works as well for these games as the Nash equilibrium prediction did in the simultaneous move games of the previous chapter.

There are several reasons why this question is interesting. Notice that in constant sum games the Nash equilibrium outcome of the normal form games and the subgame perfect equilibrium outcome of the sequential games coincide. This is because, thinking in terms of backwards induction for a game with two players, when the last mover in

[1] See, for example, McCabe et al. (1994), Mookherjee and Sopher (1994)), Stahl and Wilson (1995), Broseta et al. (2001), Brown and Rosenthal (1990), Rapapport and Boebel (1992) and Mookherjee and Sopher (1997)).

sequential games optimally chooses the action that maximizes his payoffs given the options left available, he minimizes the payoffs of the first mover and thus, a first mover optimally chooses the strategy that maximizes the minimum of his possible payoffs. This Maximin (or Minimax) strategy follows exactly the same logic as the Nash equilibrium strategy in normal form constant sum games. However, even if the theoretical outcome may coincide between the simultaneous and the sequential move games it is possible that when laboratory subjects actually play the sequential games the outcomes may differ.

A possible reason for differences in the outcomes of simultaneous and sequential games with the same payoff matrix may be that subjects may put greater weight on other regarding preferences in sequential games. This would seem particularly true for models of other regarding preferences that incorporate intentionality, as the sequentiality of the games makes clear that a second player's decision is contingent on the first player's choice and therefore, the way a second mover interprets the intentions of the strategy chosen by a first mover can clearly influence the outcome of the play. Anticipating this, a first mover may carefully select his own strategy in order to make, for example, the second mover interpret his intentions in a way that may induce him to reward supposedly kind behaviour by the first mover.

On the other hand, as we argued in the previous chapter, in constant sum games behaviour should not be affected by other regarding preferences that do not include concerns for intentionality, i.e., distributional preferences. The theoretical argument is that distributional preferences should not affect choices as long as subjects care more for their own payoffs than for those of other subjects.[2] This is because subjects who care about opponents' payoffs would have to give up the same units of payoffs that would go to their opponent in order to increase their opponents' payoffs. We showed previously that this theoretical argument, although compatible with other possible explanations, is not proven wrong by laboratory play in simultaneous constant form games. However, if we want to be more general and study for which types of games theory predictions are not affected by other regarding preferences, both with and without intentions, we precisely need to study games in which we suspect that intentions may play a role, and that is why we choose sequential constant sum games.

There is at least one type of constant sum games in which there is evidence that other regarding preferences may affect laboratory play: dictator games.[3] In them, a single subject has to allocate a fixed amount between him and another subject, with no strategic decision being taken by the receiver. When dictator games have been played in the laboratory strictly controlling for anonymity (both between subjects and

[2] Camerer et al. (1998) discuss this argument.

[3] See Hoffman, McCabe and Smith (1999) and Roth (1995).

with respect to the experimenter) there is a significant proportion of subjects who do not concord with the equilibrium prediction and allocate the minimum possible amount to the other player.[4] In our experiment, the situation faced by second movers is similar to the allocators' situation in dictator games. In fact, we could define second movers' strategic situation as "mini-dictator" games, since second movers do not have a continuous choice but they can only choose between three actions. There is a difference however between mini-dictator games and our games: when second movers in our games have to choose their action, they are limited by the action taken by first movers and therefore, intentionality and willingness to reward kind behaviour may affect their choices. In dictator games, there is no possible response to the allocator's strategy and thus, non equilibrium outcomes may be explained by distributional preferences by themselves, with no need of reciprocal or intentionally driven other regarding preferences. We are aware of two experiments with sequential constant sum games in which two players make decisions. In Falk and Kosfeld (2005) second movers decide an allocation of a constant quantity between then and a first mover, after observing whether the first mover decides to restrict or not the interval in which the second mover can decide. Thus, second movers face a dictator game situation once first movers have restricted them or not. They observe that when first movers restrict second movers, they allocate less to first movers. Thus, although the subgame perfect equilibrium prediction is not fulfilled, the "intentions"[5] signalled by whether first movers restrict or not makes a difference on second movers. Fey, McKelvey and Palfrey (1996) carried out sequential constant sum centipede games in which, at the first round, payoffs are divided evenly and, as the players pass, the division gets more and more lopsided. They observe that the subgame perfect equilibrium prediction in which the first mover takes in the first round works much better than in centipede games which are not constant sum. Therefore, we expect our results to be driven by the fact that games are constant sum and that both players can make decisions and thus, they may be signalling their intentions.

In terms of both subjects having an option to decide strategically, our games also resemble ultimatum games, in which also non subgame perfect equilibrium outcomes are frequently observed (Güth et al. (1982)). A key difference with our games is that in ultimatum games, the second mover has the clear option to punish the first mover by rejecting his allocation and leaving both players with no payoffs. In ultimatum games, such a threat would not be credible if second movers are only concerned for own payoff maximization, but it has been observed that not only a significant proportion of second movers exercise such threat, but that this threat is credible to first

[4] See Bolton and Zwick (1995) and Bolton, Katok and Zwick (1998).
[5] Referred as "trust" by the authors.

movers and they rarely allocate the minimum possible amount to second movers. The most frequent explanation for such behavior is that subjects have other regarding preferences that include intentionality. Ultimatum games are not constant sum because of the possibility of rejecting offers and leaving both players with no payoffs. In the games studied in this chapter, this possibility does not exist and in fact, the maximum "punishment" a second mover can inflict on a first mover is by choosing his own payoff maximizing strategy. However, although in constant sum games there is no possibility of punishment, second movers' intentionality driven other regarding preferences could manifest themselves in second movers rewarding kind behaviour by first movers and thus, giving up some units of payoffs in favour of first movers who have taken and action interpreted as kind by second movers. Notice that other explanations for second movers non payoff maximizing behaviour are possible and we try to discriminate between them using both the data and the results of an informal questionnaire.

There is a clear way in which subjects' choices in our games could show that subjects have other regarding preferences. As in the previous chapter, we designed a treatment in which one of the outcomes in all the games would be that payoffs were exactly equally split. In such treatment, first movers choosing strategies that may lead to the equal split outcome could be signalling to second movers their intention to split the payoffs evenly. Therefore, second movers who also choose to equally split the payoffs may be responding reciprocally to first movers' strategy. We compare whether the feasibility of exactly equally splitting the payoffs influenced subjects behaviour, by comparing choices in treatments that included the feasibility of equal splits in all ten games with choices in treatments in which such equal split was replaced by a less equal outcome, without affecting the subgame perfect equilibrium prediction. Although the feasibility of exactly equal splits have been shown to have an important effect in ultimatum games (Güth, Huck and Müller, (2001)), we find no such effects in our games.

The chapter studies how close subjects behaviour was to the subgame perfect equilibrium prediction and enquires whether subjects were able to reason in game theoretic arguments. It also includes a comparison of the results in this chapter with the previous chapter. We observe that the subgame perfect equilibrium prediction in sequential constant sum games works even better than the Nash equilibrium prediction in simultaneous constant sum games. This result indicates that even if the strategy space is more complex in sequential games, first movers seem better able to backward induct in our sequential games than to calculate Nash equilibria in the simultaneous ones. Additionally, second movers seem to be good at best responding once they observe first movers' choices.

The remainder of the chapter is organized as follows. Sections 5.2 presents the experimental design and procedures. Section 5.3 contains the results and the main descriptive statistics. Section 5.4 comments on the answers given by subjects on a voluntary questionnaire. Section 5.5 concludes. The Appendices contain the instructions and we also show the games.

5.2 Experimental Design and Procedures

5.2.1 Experimental Design

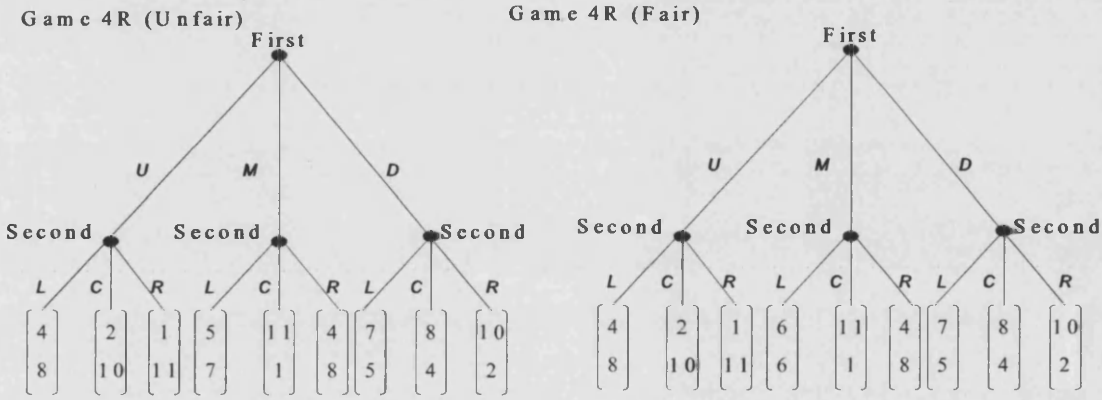
Subjects were presented with a series of ten 3x3 constant sum games with unique subgame perfect equilibria. The games had the same payoff matrix as the games in the previous chapter,[6] but the games were now played sequentially. First movers chose, for each of the ten games, one of three actions (labelled "UP", "MIDDLE" and "DOWN"). Then, second movers observed first movers' choice and picked one of their three actions available (labelled "LEFT", "CENTRE" and "RIGHT").

We constructed a 2x2 design according to two criteria. The first criterion was whether first movers' payoffs corresponded to the payoffs assigned to Column or to Row subjects in the previous experiment. By having a treatment in which first movers' payoffs corresponded to column subjects, but also another where first movers' payoffs corresponded to Row subjects, we can compare our results with the previous experiment with simultaneous play no matter the sequence of actions in this new experiment.

The second criterion, as in the previous experiment, was whether an equal split of payoffs was feasible in each of the games. As the games were constant sum, there was always the same amount of payoffs (£12) to be distributed among the two players. In the "Fair" treatments (F) an equal split of payoffs was feasible in one of the terminal nodes of each of the games subjects played. Payoffs were designed such that both subjects would get £6 if they both took the action leading to this node being reached. In the "Unfair" treatments (U), the payoffs in this terminal node were substituted by a more unequal split, such that one subject would get a payoff of £7 and the other a payoff of £5. For example, in Game 4R below, payoffs when first movers chose MIDDLE (M) and second movers chose LEFT (L) were £6 for both subjects in the Fair treatments, while they were £5 for first movers and £7 for second movers in the Unfair treatments. The location of this node and the changes in payoffs from the Fair to the Unfair treatments were designed such that in some games it was the first mover who got a better than equal split payoff in the Unfair treatments while in other games it was the second mover and such that subjects would get a higher payoff in this terminal node in some games (lower in other games) than when their

[6] The games can be found in Appendix B.

actions lead to the subgame perfect equilibrium, referred to simply as "Equilibrium" from here onwards. Notice that the terminal node in which the equal split was feasible never coincided with the terminal node that would have been chosen as a result of both subjects playing according to the subgame perfect equilibrium. Comparing the F and U treatments allows us to study whether the feasibility of an exact equal split influenced behaviour.



5.2.2 Experimental Procedures

The experiment was carried out with pen and paper in the ELSE laboratory in December 2004. Subjects were recruited by e-mail using the ELSE database, which consists of UCL undergraduate and graduate students. As we are interested in behaviour without previous experience by non-Economics trained subjects, we made sure all our subjects had not participated in previous game experiments and had not taken courses in Economics or Game Theory.

Our experiment consisted of four sessions with twenty subjects per session. In each session, ten of the subjects were randomly assigned first mover roles in all ten games, while the other ten subjects were assigned second mover roles. Neutral language was used by calling subjects "You" and their opponents "Participants in the other group".

Upon arrival, subjects were randomly assigned seats and were asked to read some preliminary instructions, which described a strategic decision situation and a 3x3 payoff matrix associated with it.[7] Therefore, although the games were played sequentially, the games were presented in similar tables as the ones in the previous experiment.[8]

[7] The strategic situations were called "Tables" in the instructions.

[8] See Appendix B for the actual presentation of the games.

This allow us to compare our results without recurring to "Presentation effects" explanations.[9] Then subjects were required to pass an Understanding Test where they had to demonstrate that they knew how to map players' actions in a game to outcomes, and outcomes to players' payoffs. Subjects were told that those who failed the test would act as "assistants" in the experiment. However, no subject failed the test in any treatment and so the over-recruited subjects were asked to assist the experimenter.[10]

Then, first movers chose their action in all ten games. After that, answer sheets were collected, reorganized and handed to second movers who could observe, for each game, the action taken by the first mover with whom they were matched in that game. Finally, second movers chose their actions in all ten games. All games were played with no feedback and the order in which each subject played the 10 games was randomized.

For each game subjects played, they were randomly and anonymously paired with a different participant from the other group. Subjects never learned who their matched participant in each game was.

Subjects were paid as follows. At the end of each session, a number from 1 to 10 was selected from a bingo urn. This number indicated for which of the 10 games all subjects would be paid.[11] Subjects were paid exactly the amount of pounds indicated in the lower left corner of the cell chosen as a result of their action and the action chosen by their matched participant in the particular game selected with the bingo urn.

Subjects were paid the sum of a £5 fixed fee, plus their earnings in the game selected. Average payments were £11 (around $17 at the time).[12] Each session lasted one hour and each subject was allocated twenty minutes to choose their action.

5.2.3 The Games

In all ten games, two subjects had to choose sequentially among three actions. First movers chose, for each of the ten games, one of three actions (labelled "UP", "MIDDLE" and "DOWN"). Then, second movers observed first movers' choice and chose one of their three actions (labelled "LEFT", "CENTRE" and "RIGHT"). Payoffs were represented by the same matrix as for the games in the previous chapter. Notice that

[9] Schotter, Weigelt and Wilson (1994), argue for same games played simultaneously or sequentially that what matters for differences in behaviour is not the actual presentation of the game but whether the instructions are explained in simultaneous or sequential form. Here, our games are different, but still we presented payoffs similarly.

[10] All subjects were informed of this.

[11] We paid subjects for one random game instead of for an aggregated measure of their answers in all 10 games to be able to maintain a one to one relationship between outcomes and payoffs.

[12] A British pound corresponded to 1.85 American dollars at the time of the experiment. Our design allowed us to provide reasonably high incentives while keeping one or two digit numbers to represent payoffs and avoiding conversion rates from experimental currency to monetary currency.

the subgame perfect equilibrium outcome for these games is the same as the Nash equilibrium outcome for the simultaneous games of the previous chapter.

We chose one-digit numbers to represent payoffs.[13] The sum of Row and Column players' payments in all cells of all games was 12.[14] The ten games were designed such that the equilibrium did not correspond to the same combination of actions by two players in more than two games.

5.3 Experimental Results

5.3.1 Descriptive Statistics

Table 1 below presents the main descriptive statistics for each game when grouping all treatments and subject roles. We report, for each of the ten games, the percentage of times the combination of first movers' and second movers' choices reached an Equilibrium outcome, as well as the percentage of first movers' actions taken according to Equilibrium and the percentage of second movers' actions that were best responses to their matched first mover's choice. Results are clear. On average, 91.5% of times, the Subgame Perfect Equilibrium was reached. First movers played Equilibrium 93.5% of the times, and second movers best responded to their matched first mover's choice in 94% of the times. Percentages were high and similar across all games.

Game	Equilibrium Played	1st Mover Equilibrium Actions	2nd Mover Best Responses
1R	90	92.5	97.5
1C	92.5	92.5	92.5
2R	85	92.5	87.5
2C	97.5	97.5	100
3R	90	95	92.5
3C	90	90	92.5
4R	92.5	92.5	92.5
4C	92.5	92.5	95
NR	90	92.5	92.5
NC	95	97.5	97.5
Average	**91.5**	**93.5**	**94**

Table 1: Descriptive statistics (percentages).

In the following sections we study these results with further detail.

[13] We did so because if subjects really chose their actions as a best response to their beliefs, calculating such best response in terms of expected payoffs may have been more difficult if numbers representing payoffs were large, and we did not want to discourage such type of behaviour.

[14] Numbers 10 and 11 were used in a few games to make it possible to discriminate models of behavior. Number 0 was not used to avoid behavior being possibly caused by aversion to getting no payoff.

5.3.2 Treatment Effects: Feasibility of Equal Splits

One of the main questions that motivated this follow-up experiment is whether intentionally driven other regarding preferences affected subjects' choices in sequential constant sum games, both when subjects played as first movers and when they played as second movers. As commented in the introduction to this chapter, our games are similar to ultimatum games, where the feasibility of equal splits has proved to affect how subjects play games (Güth et al. (2001)). In our games however, second movers do not have the option to reject proposals and thus leave both agents with no payoffs, but they have to choose between three possible allocations of payoffs between both subjects, all adding up to the same amount. In those circumstances, a choice of strategy leading to an equal split of payoffs may be an indication of concerns for the other subject's payoffs. For example, when second movers observe first movers' choices, they may want to reward an action taken by a first mover leading to an equal split with an action that gives both agents the same payoff, even if this is not optimal for payoff maximizing second movers. At the same time, first movers may anticipate this and choose actions leading to equal splits in the first place. If we observed this type of behaviour when equal splits are feasible but not when it is not, it would be an indication that subjects may have some concern for being "fair" or for how fair other subjects interpret that their own choices are. We thus study if the feasibility of equal splits affected how subjects played the games by comparing choices by first and second movers between treatments in which it was feasible to splits payoffs equally and treatments in which it was not.

Following the same procedures as in the previous experiment, we first use Fisher's Exact Probability Test (FEPT) for count data.[15] This test allows us to check if differences in observed proportions of actions chosen between a game containing equal splits ("Fair" treatment) and a game where equal splits are not feasible ("Unfair" treatment) might be expected by chance. The null hypothesis (two-tailed) is that there is no difference in the probability of playing each strategy generating the observed proportion of play of each strategy in each treatment.[16] As with all statistical tests in this thesis, we used the free software R (2003) to perform FEPTs.

We conduct FEPT separately for each game. We first compare subjects' aggregate actions for each player role (first or second movers) in each of the ten games between the Fair and Unfair treatments. Out of the 40 possible comparisons, we can never

[15] Developed by Fisher (1935), Irwin (1935) and Yates (1934).

[16] Although less common than the Chi-square test, Fisher's test requires less data in each category to be correctly calculated. Chi-square tests would require at least five subjects playing each action in each treatment which, given that most subjects chose the same actions, was not satisfied in our games. The main assumption required for both of these tests is independence between observations of the games in each treatment.

reject the null hypothesis of the underlying probability of each subject playing each of the three strategies available being equal at the 5% significance level.[17] [18] Notice in table 2 that the total number of actions taken not according with Equilibrium by first movers is very similar between the Fair and Unfair treatments and of these, the number of actions that coincided with the strategy leading to the equal split ("Fair Action") is also very similar between treatments. The same happens with the number of best responses for second movers. We finally performed Mann-Whitney tests under the null hypothesis that the median of the distribution of the number of games in which first movers chose the strategy containing the equal split was not different between the F and U treatments. We could never reject the null hypothesis at the 5% significance level.[19].

	First Movers			Second Movers		
	Non-Equilibrium Actions	Fair Actions	Percentage	Non- Best Responses	Fair Actions	Percentage
Fair Treatment	32	22	68.75%	31	7	22.58%
Unfair Treatment	29	20	68.96%	29	7	24.14%

Table 2: Percentages of Non-Equilibrium Actions and Fair Actions

Thus, we conclude the following:

Result 1: *Behaviour was not affected by the feasibility of equal splits.*

Small payoff differences between the equal and unequal split might explain Result 1. It would be worthwhile to study robustness to higher payoff differences. An alternative explanation is that the equal split was feasible (or not) in *all* the games subjects played. As subjects were only paid for one of the games, our experiment shares characteristics with experiments carried out under the strategy method, in which a weakening of the "equal split effect" has previously been observed (Güth et al. (2001)). In any case, and admitting these caveats, our results show that there are circumstances in which subjects do not change their behaviour whether equal splits are feasible or not when

[17] Although FEPT is specifically designed for small samples it is still not a very powerful test with only ten observations in each treatment. For example using this test, we cannot reject that distribution of answers (3,2,5) in one treatment is the same as the distribution (1,7,2) in another treatment at the 5% significance level. However, we can reject that it is the same as (1,8,1). The power of the test increases with the number of observations.

[18] Results of all FEPTs in this section are the same at the 10% signicance level.

[19] Same results were obtained for the null hypothesis that treatment effects did not affect the median of the distribution of the number of games in which first movers played the equilibrium strategy and also for the distribution of second movers' best responses to first movers' actions.

deciding how to share pies of given sizes, even if one of the subjects moved previous to the other.

Using these results, we will pool the data from "Fair" and "Unfair treatments to report the following statistics.

5.3.3 Actions

We here look at individual behaviour. We find that theory predictions translate well into individual behaviour. On average, first movers played according to Equilibrium in 8.5 of the 10 games, while second movers best responded to first movers' choices in 8.65 of the games. 97.5% of first movers played the Equilibrium action in 7 or more games, while 95% of second movers best responded in 8 or more games. Table 3 below shows the Cumulative Distribution Function (CDF) of the number of games for which at least first movers played according to Equilibrium predictions and the number of games for which at least second movers best responded.

Number of Games	1st Mover Equilibrium Actions	2nd Mover Best Responses
10	10	12.5
9	57.5	75
8	85	95
7	97.5	97.5
6	97.5	100
5	100	100
4	100	100
3	100	100
2	100	100
1	100	100
0	100	100

Table 3: Cummulative Distribution Function.

As we did in the previous chapter, we compared subjects' choices across games for both players' roles. We performed McNemar's tests comparing proportions of equilibrium play by first movers between each pair of games under the null hypothesis that the proportion of first movers who played equilibrium actions was the same between all pairs of games, both when grouping the F and U treatments and when not. We do not find statistically significant differences at the 5% significance level between any pair of games. The same occurs when we performed McNemar's tests under the null hypothesis that the proportion of second movers who played best responses to their first movers was not different between all pairs of games. Our results clearly differ from what we obtained in the previous chapter where the non dominance solvable games (NR and NC) showed much lower percentages on concordance to equilibrium predictions than the other games. Notice that in games NR and NC, when played in sequential form, best responding for the second mover is almost trivial as in most cases, once the first mover has chosen an equilibrium strategy, second movers would be playing the subgame perfect equilibrium no matter what they chose. This is due to the fact that in game NR once the first mover plays Equilibrium, payoffs for the second mover are exactly the same no matter what he chooses.[20]

We now compare the results of this experiment with the previous one to check if the Equilibrium prediction works better in the sequential games than in the simultaneous games. Given that in the sequential games we have first and second movers, we compare the actual percentage of times the equilibrium prediction was correct in each of the two experiments, which is the combination of both paired subjects choosing the Equilibrium action in each game. Table 4 reports the percentage of times the Equilibrium prediction was right by game, where we observe that the subgame perfect equilibrium prediction in the sequential games works better than the Nash equilibrium prediction in the simultaneous ones, for all games.[21] Chi-square tests for differences in proportions of equilibrium play between games with the same name confirm the null hypothesis that the proportions of play were different between the two experiments in all games with the same name at the 5% significance level. This result is important because, together with the results of the following section, it provides evidence that subjects may be better able to backward induct in our simple sequential games than to calculate Nash equilibria in the simultaneous ones. Although this result is partially caused by second movers observing first movers' choice and the high percentage of best responses, it seems that first movers are able to anticipate second movers' behaviour, even if the strategy space is more complicated in sequential games than in simultaneous ones.

Game	Sequential Play	Simultaneous Play
1R	90	57
1C	92.5	54
2R	85	66.5
2C	97.5	65.63
3R	90	67
3C	90	74.38
4R	92.5	76.57
4C	92.5	60.75
NR	90	48.56
NC	95	54.375
Average	91.5	62.48

Table 4: Percentage of Times the Equilibrium Prediction was Right.

[20] In game NC this only happens for one of the subject roles.

[21] Notice that the the data in the "Simultaneous Play" column, differs from data in Chapter 4, as here we compute the percentage of times the unique Nash equilibrium was reached, not the equilibrium actions.

Therefore, we conclude:

Result 2: *The Equilibrium prediction works well in constant sum games. When the games are played sequentially, the prediction is even more accurate.*

5.4 Questionnaire Answers

Given that experimental results were so close to equilibrium predictions, we wanted to check if the reasoning process subjects claimed they used to choose their actions was also close to the subgame perfect equilibrium reasoning process that Game Theory would predict. Notice that, contrary to the experiment in the previous chapter, in this experiment we did not elicit subjects' beliefs about opponents' choices. The reason was that to elicit beliefs would be more complicated in sequential games as first movers' beliefs would be conditional on their own choice. Thus, to reward the accuracy of stated beliefs conditional on first movers' choice, would require using a quadratic scoring rule in which nine probabilities had to be stated, which could be meaningless for subjects. Therefore, to investigate how subjects' reasoned when choosing their actions, we use the answers to a questionnaire distributed after the experiment in which there were no monetary incentives for truth-telling. Therefore, we cannot make a strong point of whether subjects really used the reasoning process they claimed when making their decisions, but only that at least they were able to reason in those terms in our simple games since they provided coherent explanations. Contrary to what happened in the questionnaire of the previous experiment, here subjects' answers were much less vague and it was easy to classify the. The evidence presented in this section may be useful in the ongoing debate on whether subjects are able to arrive at game theoretic arguments without previous teaching,[22] Let us remind the reader that subjects were not Economics students, nor had they previously taken any training in Game Theory.

We classified first movers' answers into four categories. "Equilibrium" corresponds to subgame perfect equilibrium reasoning. "Minimax" is self explanatory. "Fairness" corresponds to any argument in which distributional concerns were mentioned. Finally, "Other" corresponds to explanations that we were not able to classify. Second movers' answers were classified between "Best Responses", "Fairness", when they provided some argument for distributional concerns and "Not Answer" as two subjects did not fill in the voluntary questionnaire. Results are reported in Table 5.

[22] See Camerer (2003).

	1st Movers		2nd Movers
Equilibrium	65%	**Best Response**	87.5%
Minimax	22.5%		
Fairness	5%	**Fairness**	7.5%
Other	7.5%	**Not Answer**	5%

Table 5: Classification of Questionnaire Answers

For first movers, notice that even if both "Equilibrium" and "Minimax" would lead to the same choice and ultimately they both rely in expecting the second mover to choose their payoff maximizing strategy given the first mover's choice and then maximize against it, we distinguish between both kind of explanations. In total, 87.5% of first movers' explanations could be classified under one of these reasons. The criterion to separate both reasons was whether the subject's answer included a statement referring to the "maximum of the minima". For example, subject FCC2, a Medicine student in his third year, offered the following explanation:[23]

"I assumed that B participants would choose the column in which they would gain most money, so I chose the row where I would get the most if they chose their maximum strategy given my choice".

We classified this and similar statements as "Equilibrium". However subject FRR10, a Russian History student in her second year claimed:

"Compared the three rows. Looked for the lowest number in each row. Then chose which one of these was highest, which is the amount I would get paid".

We classified this statement as "Minimax". There were some cases in which the classification between the two was not so clear. For example subject FRR9, a second year Geography student, claimed:

"I know that the B participant will pick the column where they stand to make the most so I have to pick the row where the minimum I can get is higher than other rows".

This statement seems to contain both reasons, although following the criterium mentioned above we classified it as "Minimax".

In any case, what it is surprising is the small number of statements that made reference to distributional arguments. There were only two statements by first movers

[23]Subjects referred to first movers as "A participants" and to second movers as "B participants".

to distributional concerns, both of them in "Unfair" treatments, and thus, in cases where the equal split of payoffs was not feasible. These are the following:

"*Try to choose the most equal amount*", and

"*Try against 'my better judgment' to be fair in my choice of row, so that a fair amount would also be allocated to B*".

With respect to second movers, 87.5% of subjects claimed they chose best responses to the action taken by first movers. Here we show a couple of such answers:

"*For each table, there were only three options. I chose the option that would give me most money*", and,

"*Based on A's selection, I made mine with the highest number reflected in the top right corner*".

There were only three second movers who made reference to distributional concerns. Of these, we here reproduce the explanation given by subject FCR9, a Linguistics student in his fourth year, who seemed to hint on intentions driven reciprocity guiding his choices:

"*I tried to make a balance between the amount I could get and the money 'A' person could make. I rewarded as well and paid back 'A' 's decision*".

Therefore, we conclude that subjects' claims are in line with the results of the experiment and, in particular the percentage of subjects who claimed to have worried for the distribution of payoffs was low (only 6.25% of the total of subjects).

5.5 Discussion

We have confirmed that sequential constant sum games with unique subgame perfect equilibrium in which two consecutive players have three possible choices are a class of non-trivial games for which game-theoretical predictions work well, even if the games are played for the first time by subjects not trained in Economics and without previous experience in laboratory games. Comparing our results with normal form games which share the same payoff matrix we find that theory predictions work even better in the sequential games. This is most likely caused by the fact that in the sequential games second movers have the advantage of observing first movers' choices, and given that the games are constant sum, payoff maximizing for second movers is straightforward. Even if the strategy space is more complicated, and aided by the results of the informal questionnaire, we can conclude that subjects seem well able to backward induct in the sequential games while in the simultaneous games we only concluded that the Nash equilibrium prediction works well and that subjects behave strategically and believed opponents would play strategically, although the reasoning process they followed is unclear.

Contrary to our expectation, the feasibility or not of equal splits does not affect how first movers or second movers choose. This, together with the high percentages of subgame perfect equilibrium observed, provides some reassurance that in our experiment, subjects' behaviour was not affected by other regarding preferences, with or without intentions, as opposed to what has been observed in dictator and ultimatum games. Differences with respect to these games seem caused by first movers having the option to decide and by the non possibility of punishment.

Aided by the results from our informal questionnaire we conclude that it seems wrong to generally dismiss the Subgame Perfect Equilibrium outcome as a good predictor of behaviour in simple sequential games, as subjects' claims about how they reasoned were in line with standard game theoretic arguments. The results of the two experimental chapters of this dissertation suggest further research to help identify a broader class of games for which we can have some confidence that Game Theory is a good predictor of players' behaviour.

Appendices

1 Proofs of Chapter 2

Proof of Proposition 2.1

Rewards paid in the equilibrium of the game played by the agents (w_i^i, w_j^i) appear in ICC_i^{ind}. By (R2) the value of the right hand side of ICC_i^{ind} is zero and both agents obtain the same utility when they both do not work. By (U1) α and β are positive. By choosing $w_i^i - c_i = w_j^i$, the terms that compare direct utilities in ICC_i^{ind} are equal to zero and do not subtract utility in the Left Hand Side of the condition. The principal's objective is to maximize $q_i - w_i^i - w_j^i$. By setting $w_i^i = c_i$ and $w_j^i = 0$ the principal maximizes profits with ICC_i^{ind} holding.

For individual production by agent i to be an equilibrium, ICC_j^{ind} needs also to hold. The following inequalities define the off-equilibrium rewards for ICC_j^{ind}, ICC_i^{indU} and ICC_j^{indU} to hold, with $w_j^i = 0$, which is the lowest possible reward paid to agent j in equilibrium. The restrictions shown are the result of rearranging conditions ICC_j^{ind}, ICC_i^{indU} and ICC_j^{indU} and simplifying the terms that compare direct utilities. There are four cases depending on whether $w_i - c_i \lesseqgtr w_j - c_j$ and $w_i^j \lesseqgtr w_j^j - c_j$. Of these four cases, the combination $w_i - c_i < w_j - c_j$ and $w_i^j > w_j^j - c_j$ violates ICC_j^{ind} if ICC_i^{indU} and ICC_j^{indU} hold and thus this case is removed, and we are left with a$_1$), a$_2$) and b):

a) If $w_j^j - c_j \geq w_i^j$ then: $w_j^j - c_j > \frac{-\beta}{1-\beta} w_i^j$ and

a$_1$) If $w_j - c_j \geq w_i - c_i$ then: $w_i - c_i > w_i^j + \frac{\alpha}{1+\alpha}(w_j - w_j^j)$ and $w_j - c_j < \frac{\beta}{1-\beta}(c_i - w_i)$,

a$_2$) If $w_j - c_j < w_i - c_i$ then: $w_i - c_i > \frac{1}{1-\beta}[(1+\alpha)w_i^j - \beta(w_j - c_j) - \alpha(w_j^j - c_j)]$ and $w_j - c_j < \frac{\alpha}{1+\alpha}(w_i - c_i)$.

b) If $w_i^j > w_j^j - c_j$ then: $w_i - c_i > w_i^j + \frac{\beta}{1-\beta}(w_j^j - c_j)$, $w_j - c_j < \frac{\alpha}{1+\alpha}(w_i - c_i)$ and

$$w_j^j > c_j + \tfrac{\alpha}{1+\alpha} w_i^j.$$

Proof of Proposition 2.2

Agent i's utility when he does not work, given that agent j works is:

$$w_i^j - \alpha \max\left[w_j^j - c_j - w_i^j, 0\right] - \beta \max\left[w_i^j - w_j^j + c_j, 0\right].$$

Notice that inequity aversion imposes that an agent obtains disutility either from being better off or worse off than the other agent, but not from both at the same time.

a) If agent i is worse off than agent j, the effect of *envy* dominates and $w_j^j - c_j - w_i^j \geq 0$. Thus, to minimize the utility of agent i when he does not work, $w_i^j = 0$, as the derivative of agent i's utility with respect to the reward offered to agent j equals $1 + \alpha > 0$, by assumption (U1).

b) If agent i is better off than agent j, the effect of *guilt* dominates and $w_i^j - w_j^j + c_j \geq 0$. Thus, to minimize the utility of agent i when he does not work, $w_i^j = 0$, as the derivative of agent i's utility with respect to the reward offered to agent j equals $1 - \beta > 0$, by assumption (U2).

Proof of Proposition 2.3

By *Proposition* 2.2, the reward that maximizes agent j's punishment when agent i individually works is $w_j^i = 0$.

The utility of agent j when agent i individually works is thus equal to:

$$-\alpha \max\left[w_i^i - c_i, 0\right] - \beta \max\left[-w_i^i + c_i, 0\right]$$

where by (R1) and (R2),

$$w_i^i \in [0, q_i],$$

and by (C),

$$0 \leq c_i \leq q_i.$$

Thus, minimizing agent j's utility implies:

$$w_i^i = q_i \quad \text{if} \quad \alpha(q_i - c_i) \geq \beta c_i$$

and

$$w_i^i = 0 \quad \text{if} \quad \alpha(q_i - c_i) < \beta c_i.$$

Proof of Proposition 2.4

First, from *Proposition 2.2* it is optimal not to reward agents when they shirk, in order to create incentives for both agents to work.

$$w_i^j = w_j^i = 0.$$

We now show the remaining rewards in each of the three cases referred in Proposition 2.4.

Case *a):* If $\alpha(q_i - c_i) \geq \beta c_i$ for $i = 1, 2$, it is optimal to choose $w_i^i = q_i$. Conditions (ICC^{JPU})s hold using results in *Proposition* 2.2. The principal maximizes $1 - w_1 - w_2$ subject to both (ICC^{JP})s. Using the slopes of the indifference curves given by (U1) and (U2), the conditions optimally hold with equality and profits are maximized at the unique point at which the indifference curves intersect. Let j be the agent for whom $q_j - c_j \geq q_i - c_i$, then:

$$w_i = c_i - \frac{\alpha^2(q_i - c_i) - \alpha(\beta - 1)(q_j - c_j)}{\alpha + (1 - \beta)} < c_i \qquad w_i^i = q_i,$$

$$w_j = c_j + \frac{\alpha\beta(q_j - c_j) - \alpha(1 + \alpha)(q_i - c_i)}{\alpha + (1 - \beta)} \gtreqless c_j \qquad w_j^j = q_j.$$

Case *b):* If $\alpha(q_i - c_i) < \beta c_i$ and $\alpha(q_j - c_j) \geq \beta c_j$ for $i, j = 1, 2$, $i \neq j$, it is optimal to choose $w_i^i = 0$ and $w_j^j = q_j$. The two cases are created by whether the intersection of both indifference curves occurs at a point where $w_i - c_i \lesseqgtr w_j - c_j$.

- Let $\alpha(q_i - c_i) < \beta c_i$ and $\alpha(q_j - c_j) \geq \beta c_j$: Then

$$w_i^i = 0 \quad w_j^j = q_j, \quad \text{and:}$$

- For $\alpha(q_j - c_j) \geq \beta c_i$ then:

$$w_i = c_i - \frac{\alpha\beta c_i + \alpha(1 - \beta)(q_j - c_j)}{\alpha + (1 - \beta)} < c_i \qquad w_j = c_j + \frac{\alpha\beta(q_j - c_j) - \beta(1 + \alpha)c_i}{\alpha + (1 - \beta)} \gtreqless c_j.$$

- For $\alpha(q_j - c_j) < \beta c_i$ then:

$$w_i = c_i + \frac{\beta^2 c_i - \alpha(1 + \alpha)(q_j - c_j)}{\alpha + (1 - \beta)} > c_i \qquad w_j = c_j - \frac{\alpha^2(q_j - c_j) + \beta(1 - \beta)c_i}{\alpha + (1 - \beta)} < c_j.$$

Case *c):* If $\alpha(q_i - c_i) < \beta c_i$ for $i = 1, 2$, inequity off equilibrium would be maximized by setting $w_i^i = 0$ and $w_j^j = q_j$. However the equilibrium of the game played by the agents would not be unique. Inequity off-equilibrium has to be the maximum possible subject to one of the agents obtaining higher utility when he individually works than when he does not. Thus, one of the agents is offered a reward equal to all available output when he individually works instead of no reward. Therefore, off-equilibrium one agent suffers the maximum effect of *guilt* when he shirks while the other suffers the maximum effect of *envy* ($w_i^i = 0$ and $w_j^j = q_j$ for $i, j = 1, 2,\ i \neq j$). Thus, one of the indifference curves is satisfied at the "optimal" level (for the agent who suffers *guilt* when he shirks) while the other is satisfied at the "suboptimal" level (for the agent who suffers *envy* when he shirks). The optimal rewards paid are obtained at the intersection of one of the "optimal" and one of the "suboptimal" indifference curves. The conditions indicate for which of the four possible cases, profits are maximized.

- Let $\alpha(q_i - c_i) < \beta c_i$, $\alpha(q_j - c_j) < \beta c_j$. Then for $c_j \geq c_i$:
  - For $\alpha(q_j - c_j) \geq \beta c_i$:
    - if $(1 - 2\beta)[\alpha(q_j - c_j) - \beta c_j] \geq (1 + 2\alpha)[\alpha(q_i - c_i) - \beta c_i]$, then:

$$w_i = c_i - \tfrac{\alpha\beta c_i + \alpha(1-\beta)(q_j - c_j)}{\alpha + (1-\beta)} < c_i \qquad w_i^i = 0,$$

$$w_j = c_j + \tfrac{\alpha\beta(q_j - c_j) - \beta(1+\alpha)c_i}{\alpha + (1-\beta)} \lesseqqgtr c_j \qquad w_j^j = q_j,$$

    - if $(1 - 2\beta)[\alpha(q_j - c_j) - \beta c_j] < (1 + 2\alpha)[\alpha(q_i - c_i) - \beta c_i]$, then:

$$w_i = c_i - \tfrac{\alpha^2(q_i - c_i) + \beta(1-\beta)c_j}{\alpha + (1-\beta)} < c_i \qquad w_i^i = q_i,$$

$$w_j = c_j + \tfrac{\beta^2 c_j - \alpha(1+\alpha)(q_i - c_i)}{\alpha + (1-\beta)} \lesseqqgtr c_j \qquad w_j^j = 0.$$

  - For $\alpha(q_j - c_j) < \beta c_i$:
    - if $\alpha(1 + 2\alpha)(q_j - c_j - q_i + c_i) \geq \beta(1 - 2\beta)(c_j - c_i)$, then:

$$w_i = c_i + \tfrac{\beta^2 c_i - \alpha(1+\alpha)(q_j - c_j)}{\alpha + (1-\beta)} > c_i \qquad w_i^i = 0,$$

$$w_j = c_j - \tfrac{\alpha^2(q_j - c_j) + \beta(1-\beta)c_i}{\alpha + (1-\beta)} < c_j \qquad w_j^j = q_j,$$

    - if $\alpha(1 + 2\alpha)(q_j - c_j - q_i + c_i) < \beta(1 - 2\beta)(c_j - c_i)$, then:

$$w_i = c_i - \tfrac{\alpha^2(q_i - c_i) + \beta(1-\beta)c_j}{\alpha + (1-\beta)} < c_i \qquad w_i^i = q_i,$$

$$w_j = c_j + \tfrac{\beta^2 c_j - \alpha(1+\alpha)(q_i - c_i)}{\alpha + (1-\beta)} \lesseqqgtr c_j \qquad w_j^j = 0.$$

Proof of Corollary 2.1

From *Proposition* 2.4, there are three possible cases:

-If $w_i = c_i - \dfrac{\alpha(\beta - 1)(q_j - c_j) - \alpha^2(q_i - c_i)}{\beta - 1 - \alpha}$, $w_j = c_j - \dfrac{\alpha\beta(q_j - c_j) - \alpha(1 + \alpha)(q_i - c_i)}{\beta - 1 - \alpha}$ then

$$w_i+w_j = c_i+c_j-\frac{\alpha(1-2\beta)(q_j-c_j)+\alpha(1+2\alpha)(q_i-c_i)}{\beta-1-\alpha} < c_i+c_j \text{ by(C), (U1) and (U2).}$$

- If $w_i = c_i-\dfrac{\alpha\beta c_i+\alpha(1-\beta)(q_j-c_j)}{1+\alpha-\beta}$ and $w_j = c_j-\dfrac{\beta(1+\alpha)c_i-\alpha\beta(q_j-c_j)}{1+\alpha-\beta}$ then,

$$w_i+w_j = c_i+c_j+\frac{(1+2\alpha)\beta c_i+\alpha(1-2\beta)(q_j-c_j)}{\beta-1-\alpha} < c_i+c_j \text{ by (C), (U1) and (U2).}$$

- If $w_i = c_i-\dfrac{\alpha(1+\alpha)(q_j-c_j)-\beta^2 c_i}{1+\alpha-\beta}$ and $w_j = c_j-\dfrac{\beta(1-\beta)c_i+\alpha^2(q_j-c_j)}{1+\alpha-\beta}$ then,

$$w_i+w_j = c_i+c_j+\frac{\alpha(1+2\alpha)(q_i-c_i)+\beta(1-2\beta)c_j}{\beta-1-\alpha} < c_i+c_j \text{ by (C), (U1) and (U2).}$$

Proof of *P*roposition 2.5

Rewards paid in the equilibrium of the game (w_i^i, w_j^j) appear in ICC_i^{ind} and ICC_j^{ind}. By (R2) the value of the right hand side of ICC_i^{ind} is zero and both agents obtain the same utility when they both do not work. As $\alpha > 0$, the only possible way to make condition ICC_i^{ind} hold under a lower total reward cost is by setting $w_i^i - c_i \geq w_j^i$. However, by (R1), $w_j^i \geq 0$, and thus, $w_i^i \geq c_i$. The minimum reward needed to be paid in equilibrium are thus $w_i^i = c_i$ and $w_j^i = 0$.

Proof of Proposition 2.6

As $\beta < 0$, agents only obtain disutility from *envy*. To maximize the effect of *envy* off the joint production equilibrium, the agent who does not work off equilibrium is offered no reward ($w_i^j = 0$ for $i, j = 1, 2$ and $i \neq j$) and the agent who works is offered all available production ($w_i^i = q_i$ for $i = 1, 2$). The expression for the equilibrium rewards paid follows calculations in case *a)* in *Proposition* 2.4.

Proof of Proposition 2.7

Assume agent i individually works off the equilibrium of the game. Efficiency concerns implies that agents care for the weighted sum of direct utilities, putting more weight on each own's direct utility than on the other agent's direct utility:

a) If $U_j \geq U_i$, agent i's utility can be written as $(1+\alpha)U_i - \alpha U_2$, which is a weighted sum since $\alpha < 0$ and $|\alpha| < \frac{1}{2}$.

b) If $U_j < U_i$, agent i's utility can be written as $(1-\beta)U_i + \beta U_2$, which is a weighted sum since $\beta \in [0, \frac{1}{2})$.

For ICC_i^{ind} to hold, agent i must obtain non-negative utility when he works given that agent j does not work. Assume $w_i^i < c_i$, then it is necessary that $w_j^i > c_i - w_i^i$

as $|\alpha| < \frac{1}{2}$. Obviously, given (R1), this implies $w_i^i + w_j^i \geq c_i$. Finally, $w_i^i \geq c_i$ cannot be optimal as it implies $w_i^i + w_j^i \geq c_i$. Notice that $w_i^i = c_i$ and $w_j^i = 0$ is not the only possible combination such that the condition holds.

Proof of Proposition 2.8

To maximize the effect of inefficiency off-equilibrium, all agents should be offered no reward off-equilibrium, no matter whether they work or not. However, by doing so, no production would be an equilibrium as ICC_i^{JPU} for $i = 1, 2$ would not hold. Thus, working has to be a dominant strategy for one of the agents (agent i). For ICC_i^{JPU} to hold but at the same time not provide incentives for agent j to shirk when agent i individually works, it is optimal to set $w_i^i = c_i$ and $w_j^i = 0$. When agent j individually works, maximum inefficiency is generated by setting $w_i^j = w_j^j = 0$. The remaining two equilibrium rewards are obtained at the intersection between the minimum lines defined by both ICC_i^{JP}'s for $i = 1, 2$:

$$
\begin{aligned}
w_i - c_i - \beta(w_i - c_i - w_j + c_j) &\geq 0, \\
w_j - c_j - \alpha(w_i - c_i - w_j + c_j) &\geq -\beta c_i,
\end{aligned}
$$

which yields: $w_i = c_i + \frac{\beta^2}{1+\alpha-\beta}c_i$ and $w_j = c_j - \frac{\beta(1-\beta)}{1+\alpha-\beta}c_i$.

Notice that the sum of rewards paid in equilibrium equals $w_i + w_j = c_i + c_j - \frac{\beta(1-2\beta)}{1+\alpha-\beta}c_i$. As $\alpha < 0$, $\beta \in [0, 1/2)$, and $|\alpha| \leq |\beta|$ then $\frac{\beta(1-2\beta)}{1+\alpha-\beta} > 0$ and thus, it is optimal to set $w_j^j = c_j$ for the agent for which the cost of effort is lowest, i.e., for $c_j > c_i$ and $i, j = 1, 2$, $i \neq j$.

2 Numerical examples of Chapter 2

2. 1 Change of optimal production level

Assume $\alpha = 0.9, \beta = 0.1, q_1 = 0.7, c_1 = 0.5, q_2 = 0.5$ and $c_2 = 0.4$.

The condition for individual production by agent 1 to be optimal, $1 - c_2 \leq q_1 \quad if \quad (q_1 - c_1) > (q_2 - c_2)$, holds as $1 - 0.4 \leq 0.7$ with $(0.7 - 0.5) > (0.5 - 0.4)$. Therefore, in the equilibrium of the game when agents are standard rewards paid are $w_1^1 = 0.5$ and $w_2^1 = 0$, and profits $(q_1 - w_1^1)$ are equal to 0.2.

Now we look at joint production with inequity averse agents. From *Proposition* 2.3, it is optimal to offer $w_1^2 = w_2^1 = 0$ to the agent who does not work when the other agent individually works. Notice also that $\alpha(q_i - c_i) > \beta c_i$ for $i = 1, 2$, as:

$$
\begin{gathered}
0.9(0.7 - 0.5) > 0.1(0.5) \\
0.9(0.5 - 0.4) > 0.1(0.4).
\end{gathered}
$$

Thus, it is optimal to offer all output to the agent who individually works off equilibrium: $w_1^1 = q_1 = 0.7$ and $w_2^2 = q_2 = 0.5$.

Finally, notice that $\alpha(q_1 - c_1) > \alpha(q_2 - c_2)$ as $0.18 > 0.09$. Thus, in equilibrium $w_1 - c_1 > w_2 - c_2$ and the ICC_i^{JP}s are:

$$w_1 - 0.5 - 0.1(w_1 - 0.5 - w_2 + 0.4) \geq -0.09$$
$$w_2 - 0.4 - 0.9(w_1 - 0.5 - w_2 + 0.4) \geq -0.18.$$

Solving these two inequalities with equality, we obtain the optimal equilibrium rewards for joint production, $w_1 = 0.415$ and $w_2 = 0.265$. Thus, profits when joint production is implemented are equal to $1 - w_1 - w_2 = 0.32$, which are higher than profits with individual production by agent 1 as $0.32 > 0.2$. Therefore, joint production is optimal when agents are inequity averse while individual production by agent 1 is optimal when agents are standard.

2.2 Principal's loss when joint production is not optimally implemented

Assume $q_1 = q_2 = 0.5$ and $c_1 = c_2 = 0.4$.

The condition for joint production to be optimal when agents are standard, $1 - q_1 \geq c_2$ if $(q_1 - c_1) \geq (q_2 - c_2)$ holds, as $1 - 0.5 \geq 0.4$ with $(0.5 - 0.4) \geq (0.5 - 0.4)$.

Thus, with standard preferences the total cost of implementing joint production equals the sum of both agents' costs of effort: $w_1 + w_2 = c_1 + c_2 = 0.8$.

When agents are inequity averse, the agent who individually works off equilibrium is offered a reward equal to total individual production, $w_i^i = q_i$ if $\alpha(q_j - c_j) \geq \beta c_j$ for $i, j = 1, 2, i \neq j$. Thus, there are two cases:

a) If $\alpha(0.5 - 0.4) \geq \beta(0.4) \Rightarrow \alpha \geq 4\beta$ then: $w_1^1 = w_2^2 = 0.5$,
b) If $\alpha(0.5 - 0.4) < \beta(0.4) \Rightarrow \alpha < 4\beta$ then: $w_1^1 = w_2^2 = 0$.

a) Assume $\alpha \geq 4\beta$. The no deviation conditions for each agent to work when the other agent works are:

$$w_1 - 0.4 - \alpha \max[w_2 - 0.4 - w_1 + 0.4, 0] - \beta \max[w_1 - 0.4 - w_2 + 0.4, 0] \geq -\alpha[0.5 - 0.4],$$
$$w_2 - 0.4 - \alpha \max[w_1 - 0.4 - w_2 + 0.4, 0] - \beta \max[w_2 - 0.4 - w_1 + 0.4, 0] \geq -\alpha[0.5 - 0.4].$$

As the productivity parameters are the same for both agents, in equilibrium there is no inequity and equilibrium rewards are:

$$w_1 = w_2 = 0.4 - 0.1\alpha.$$

b) Assume $\alpha < 4\beta$. The no deviation conditions for each agent to work when the other agent works are:

$$w_1 - 0.4 - \alpha \max[w_2 - 0.4 - w_1 + 0.4, 0] - \beta \max[w_1 - 0.4 - w_2 + 0.4, 0] \geq -\beta(0.4),$$
$$w_2 - 0.4 - \alpha \max[w_1 - 0.4 - w_2 + 0.4, 0] - \beta \max[w_2 - 0.4 - w_1 + 0.4, 0] \geq -\beta(0.4).$$

As the productivity parameters are the same for both agents, in equilibrium there is no inequity and equilibrium rewards are:

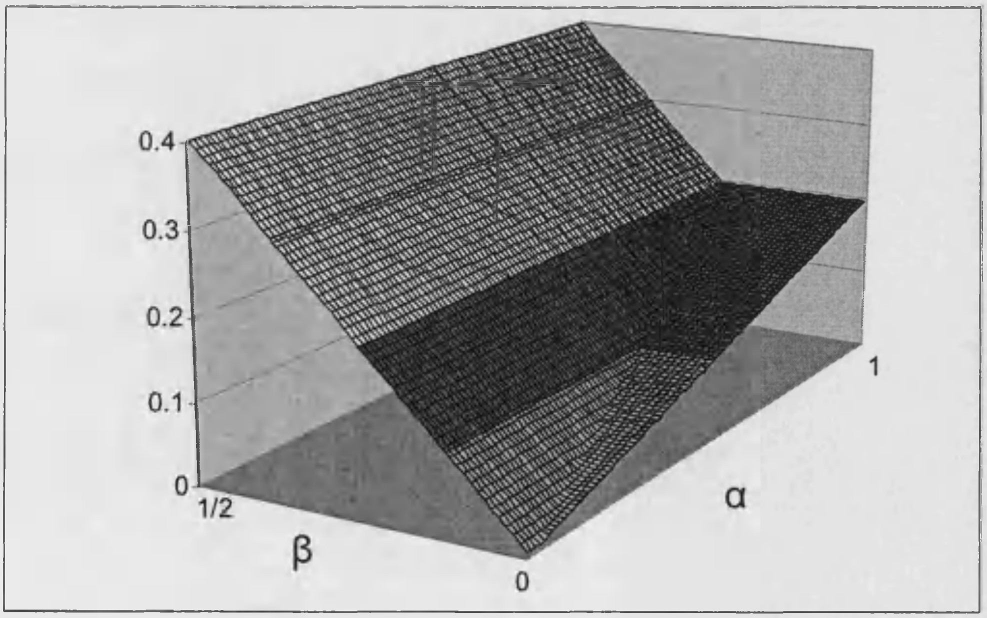
$$w_1 = w_2 = 0.4(1 - \beta).$$

We calculate the principal's possible loss as the difference between the principal's profits (production minus rewards) with and without inequity aversion. As production when both agents work is normalized to 1, this loss is expressed in terms of the total production exerted.

Thus, the loss function is

$$\begin{array}{ll} [1 - 2(0.4 - 0.1\alpha)] - [1 - 0.8] & \text{when } \alpha \geq 4\beta, \\ [1 - 2(0.4)(1 - \beta)] - [1 - 0.8] & \text{when } \alpha < 4\beta. \end{array}$$

The figure below displays this loss function for $\alpha \in [0, 1)$ and $\beta \in [0, \frac{1}{2}]$.



Principal's loss when $q_1 = q_2 = 0.5$ and $c_1 = c_2 = 0.4$.

3 Proofs of Chapter 3

In this appendix we sketch the equilibrium solutions of the game with exogenous sequential moves and incomplete information and the game with endogenous timing and incomplete information.

The game with exogenous sequential moves can be solved by simple backward induction (since the first mover only influences the second mover's payoff via his action and not via his type). The low type ($b = 0$) will simply choose

$$x_2^L = k$$

in the second period regardless of what the first mover did. The high type ($b = \overline{b}$) would instead react to the leader's decision and choose his effort according to

$$x_2^H(x_1) = \frac{k + \overline{b}x_1}{1 + \overline{b}}.$$

As first movers both types would utilize the commitment effect. Specifically, the low type would choose

$$x_1^L = k\frac{1 + \overline{b}(1 + p)}{1 + \overline{b}}$$

and the high type

$$x_1^H = k\frac{1 + 3\overline{b}(1 + \overline{b}) + \overline{b}p(1 - \overline{b}) + \overline{b}^3(1 - p)}{1 + 3\overline{b}(1 + \overline{b}) - 2\overline{b}^2 p + \overline{b}^3(1 - p)}.$$

This also describes what would happen in one of the asymmetric equilibria of the game with endogenous timing, where one of the agents becomes leader because of his "name".

We conclude this appendix by mentioning the first-period effort that a high type would choose deviating from a proposed symmetric outcome where low types move first and high types second. The optimal deviation would then be to choose

$$x_1^+ = k\frac{1 + 3\overline{b}(1 + \overline{b}) + \overline{b}p(1 - \overline{b}p) + \overline{b}^3(1 - p^2)}{1 + 3\overline{b}(1 + \overline{b}) - 2\overline{b}^2 p + \overline{b}^3(1 - p)}.$$

4 Instructions for Chapter 4 (BABA Treatments)

WELCOME TO OUR EXPERIMENT!

This is a serious scientific experiment and, as such, no talking, looking around or walking around will be permitted. If you have any questions or need any assistance, please raise your hand and an experimenter will come to you. If you talk, exclaim out loud, etc, YOU WILL BE ASKED TO LEAVE AND YOU WILL NOT BE PAID. Thank you.

This is an experiment on individual decision making. The ESRC Centre for Evolutionary Learning and Social Evolution (ELSE) has provided the funds for this experiment. You will be paid £5 (five pounds) for having arrived on time. Additionally, if you follow the instructions and pass an Understanding Test you will be allowed to continue in the experiment. Once in the experiment, depending on your decisions you may earn a considerable additional amount of money. This additional amount will be determined both by your decisions and by those of other participants in the experiment. Before making your decisions, you will be informed about how your earnings and the other participants' earnings depend on your and their decisions. All that you earn is yours to keep, and will be paid to you in private, in cash, after today's session.

We need 20 people for this session. Thus, if more than 20 people pass the Understanding Test, some of you will be asked not to participate in the experiment but to help the experimenter as "assistants". These assistants will check that everything is done as explained in the instructions. The assistants will be paid the average of the payments of the 20 participants in the experiment.

For each decision you take in the experiment, You will be anonymously matched with one of the other participants. We will refer to the other participants as "S / HE". You and s/he will be presented with a TABLE. For this table, You and S/HE separately and independently will make a DECISION. Together, the two decisions determine the number of POUNDS each of you earns, which may be different.

The table in the next page shows an illustrative example. IT IS ONLY AN ILLUSTRATION. The tables you will see during the experiment will be different from this one. AS YOU LOOK AT THIS TABLE, PLEASE CONTINUE READING THIS HANDOUT FOR INSTRUCTIONS ON HOW TO UNDERSTAND THE TABLE:

S / HE

		LEFT	CENTRE	RIGHT
	UP	9 1	8 2	7 3
YOU	MIDDLE	6 4	5 5	4 6
	DOWN	3 7	2 8	1 9

In the actual experiment, you will be shown tables like this one (but with different numbers), and asked to choose one of your decisions ("UP", "MIDDLE" or "DOWN"). The participant to whom you are matched for each table will be asked, independently, to choose one of her/his decisions ("LEFT", "CENTRE" or "RIGHT").
The combination of your decision and her/his decision determines the cell of the table chosen. The number of pounds you and s/he receive for the cell chosen is a whole number ranging from 1 to 11.
The number of pounds you receive appears in the lower left corner of each cell of the table.
The number of pounds s/he receives appears in the upper right corner of each cell of the table.
To interpret the table, consider the results of the possible combinations of decisions.

-If you choose UP and S/HE chooses LEFT, you earn 1 Pound and S/HE earns 9 Pounds.
-If you choose UP and S/HE chooses CENTRE, you earn 2 Pounds and S/HE earns 8 Pounds.
-If you choose UP and S/HE chooses RIGHT, you earn 3 Pounds and S/HE earns 7 Pounds.
-If you choose MIDDLE and S/HE chooses LEFT, you earn 4 Pounds and S/HE earns 6 Pounds.
-If you choose MIDDLE and S/HE chooses CENTRE, you earn 5 Pounds and S/HE earns 5 Pounds.
-If you choose MIDDLE and S/HE chooses RIGHT, you earn 6 Pounds and S/HE earns 4 Pounds.
-If you choose DOWN and S/HE chooses LEFT, you earn 7 Pounds and S/HE earns 3 Pounds.
-If you choose DOWN and S/HE chooses CENTRE, you earn 8 Pounds and S/HE earns 2 Pounds.
-If you choose DOWN and S/HE chooses RIGHT, you earn 9 Pounds and S/HE earns 1 Pound.

Please be sure you understand this table. Raise your hand if you would like further explanation. Otherwise, please start with the Understanding Test in the next page. Please raise your hand once you have finished the Understanding Test.

UDERSTANDING TEST

You will now take a short UNDERSTANDING TEST. After you have finished the TEST, it will be graded and you will ONLY be allowed to continue in the experiment if you have answered ALL the QUESTIONS CORRECTLY. If one or more of your answers is not correct, we will ask you to be our assistant and to check that everything proceeds as explained in the instructions. Notice that even if all your answers are correct, you may be asked to be our assistant.
This test has 5 questions. After you have answered all 5 questions, please re-check your answers. Please raise your hand when you are finished so as we can grade this test.

S / HE

		LEFT	CENTRE	RIGHT
	UP	6 2	3 7	4 5
YOU	MIDDLE	8 9	9 6	2 4
	DOWN	1 1	5 3	7 3

Using the table above, please answer the following questions.

Questions:

1. If you choose MIDDLE and S/HE chooses RIGHT, how many Pounds will you earn?

2. If you choose UP and S/HE chooses LEFT, how many Pounds will S/HE earn?

3. If you choose UP and S/HE chooses RIGHT, how many Pounds will you earn?

4. If you choose DOWN and S/HE chooses CENTRE, how many Pounds will you earn?

5. If you choose DOWN and S/HE chooses LEFT, how many Pounds will S/HE earn?

YOU HAVE JUST COMPLETED THE TEST.
Please re-check your answers and raise your hand when you are done.

INSTRUCTIONS

There are 20 participants in this experiment. We have randomly divided the 20 participants in two groups of 10 participants. Everyone has been recruited for this experiment using the same procedure and everyone is receiving the same instructions.
In this experiment we are going to show you 10 different tables, similar to the one you have already seen.
For each table, you will have to answer two questions. One question asks you to choose a decision and the other question asks you about what you THINK other people's decisions are. Below we explain how to answer these questions and how you will be paid for your answers.

For each table, you have to choose between "UP", "MIDDLE" and "DOWN".
The 10 participants in the other group, choose between "LEFT", "CENTRE" and "RIGHT" in each of the 10 tables.

For the first question, you will have to write down how many of the 10 participants in the other group YOU THINK have chosen each of their 3 options (LEFT, CENTRE and RIGHT) in each of the 10 tables.

For the second question, you have to circle your decision (UP, MIDDLE or DOWN) in each of the 10 tables.
Notice that for each of the 10 tables, you have been anonymously and randomly matched with one of the 10 participants in the other group (who chooses between "LEFT", "CENTRE" and "RIGHT").
YOU HAVE BEEN MATCHED WITH A DIFFERENT PARTICIPANT IN EACH TABLE.
None of the participants will know who they are matched with in each table.

Lets see an example on how to answer the 2 questions:

In the table below I have written down that out of the 10 participants in the other group, I THINK 4 will choose "LEFT", I THINK 1 will choose "CENTRE" and I THINK 5 will choose "RIGHT". (Notice that guesses about how others play must always add up to 10).
Also, I have circled "MIDDLE" to indicate that "MIDDLE" is my decision.

Example:
Out of the 10 participants in the other group I think they will choose:

LEFT	CENTRE	RIGHT	TOTAL
__4___	__1___	__5___	__10__

		S/HE LEFT	CENTRE	RIGHT
	UP	5 2	4 8	3 4
YOU	MIDDLE	7 5	4 11	3 7
	DOWN	9 3	11 1	8 5

Caution: The numbers used in this example were selected arbitrarily.They are NOT intended to suggest how anyone might respond in any situation.

Below we explain how we will pay you according to your answers and the answers of your matched participant to each of the 2 questions.

PAYMENT FOR YOUR ANSWERS TO QUESTION 1

You will be paid an amount of money according to the difference between the number of participants in the other group you have guessed have chosen each option ("LEFT", "CENTRE" or "RIGHT") and the actual number of participants in the other group who have in fact chosen each decision.
We will pay you according to a formula that we explain below. Do not worry if the formula seems complicated as it is not important that you understand the workings of the formula completely. However, notice that with this formula, the closer the numbers you write down (your "guesses") to the actual number of participants who have chosen each decision in each table, the more money you will get.
For example, if 6 participants have chosen LEFT and you guessed that 6 participants would choose LEFT, you would get more money than if you guessed that 5 or 7 participants would choose LEFT for that table.

Here is the formula:

$$Payment = 2 - 0.01 * [(a - X)^2 + (b - Y)^2 + (c - Z)^2]$$

Where:

a: Number of participants you think have chosen LEFT — *X: Number of participants who have chosen LEFT*

b: Number of participants you think have chosen CENTRE — *Y: Number of participants who have chosen CENTRE*

c: Number of participants you think have chosen RIGHT — *Z: Number of participants who have chosen RIGHT*

Please follow the next examples to see how the formula works.

Examples:

-In some table, you write that you think 7 participants have chosen LEFT, 0, participants have chosen CENTRE and 2 participants have chosen RIGHT. If, in fact, 7 participants have chosen UP, 0 participants have chosen CENTRE and 2 participants have chosen RIGHT, you get:

$$Payment = 2 - 0.01* [(7-7)^2 + (0-0)^2 + (2-2)^2] = 2- 0.01*[0] = \mathbf{2\ Pounds.}$$

- In some other table, you write that you think, 5 participants have chosen LEFT, 2 participants have chosen CENTRE and 3 participants have chosen RIGHT. If, in fact, 1 participant has chosen UP, 8 participants have chosen CENTRE and 1 participant has chosen RIGHT, you get:

$$Payment = 2 - 0.01 [(5-1)^2 + (2-8)^2 + (3-1)^2] = 2 - 0.01[4^2 + 6^2 + 2^2] =$$
$$= 2 - 0.01*[56] = \mathbf{1.44\ Pounds}$$

- Finally, in some other table, you write that you think, 0 participants have chosen LEFT, 10 participants have chosen CENTRE and 0 participants have chosen RIGHT. If, in fact, 10 participants have chosen UP, 0 participants have chosen CENTRE and 0 participants have chosen RIGHT, you get:

$$Payment = 2 - 0.01\ [(0\text{-}10)^2 + (10\text{-}0)^2 + (0\ \text{-}0)^2] = 2 - 0.01[0] = \mathbf{0\ Pounds}$$

Caution: The numbers used in this example were selected arbitrarily. They are NOT intended to suggest how anyone might respond in any situation.

These examples should illustrate that with this formula you will always receive a payment of at least £0 and at most £2 for question 1 and that you will earn more money the more accurate your written guesses are.

PAYMENT FOR YOUR ANSWERS TO QUESTION 2

You will be paid a number of pounds equal to the number that appears in the lower left corner of the cell that you and your matched participant in that table have chosen. Your matched participant in the table will be paid the amount of pounds that appears on the upper right corner of the cell that you and her/him have chosen.

FINAL INSTRUCTIONS

We will wait until all participants have finished answering the 2 questions in the 10 tables. Please take some time to think and check your answers. We will allow a maximum of 40 minutes to answer all questions. **Please, if you finish before time raise your hand and we will collect your answers.** However, you are asked to remain in your seat quiet until all participants have finished.
After all participants have finished, we will randomly select ONE table from which all payments to all participants will be done. This table will be selected using a bingo urn with 10 numbered balls. The number on the ball selected determines for which of the 10 tables all participants are paid for both question 1 and question 2.
You will be paid the sum of three things:

- £5 for arriving on time
- The result of applying the formula explained in question 1 to the selected table.
- The amount of pounds indicated in the lower left corner of the cell that you and your matched participant in the selected table have chosen.

You have been given an identification number. Please write this number at the top of each of your answer sheets and keep the number. You will need this number to be paid.
While we calculate the payments you will be asked to fill in an anonymous questionnaire. After we have done the calculations, you will be asked to come with the questionnaire and your identification number to a room where you will be paid your earnings in cash and in private.

PLEASE WAIT UNTIL THE EXPERIMENTER TELLS YOU TO START
(Please raise your hand if there are any doubts with these instructions, and we will answer them privately)

5 The Games in Chapter 4

Below we show each of the ten games subjects played in treatments BABAU and ABU. Below each game we indicate the cells that were changed to create treatments BABAF and ABF. Additionally, we indicate the predictions of each of the six models studied ("Eq" for Equilibrium, "Max" for Maximax, other names are identical), the percentage of subjects who played each action ("Act"), the percentage of beliefs assigned to that action ("Bel") and the round of iterated strict dominance in which a strategy would be deleted (*"Do1", "Do2", "Do3"* and *"Do4")*.

Game 1R

Column

Row		Left *Do2*	Centre *Do2*	Right	
	Up *Do1*	9 3	8 4	7 5	Act: 0 Bel: 3
	Middle *Do1*	7 5	5 7	5 7	Act: 20 Bel: 15.25
	Down	L1 3 Max 9	3 9	Eq 4 L2 8 L3 D1	Act: 80 Bel: 81.75
		Act: 22.5 Bel: 40.75	Act: 5 Bel: 24	Act: 72.5 Bel: 35.25	

In treatments BABAF and ABF, the Middle-Left Payoff was changed by (6,6).

Game 1C

Column

Row		Left *Do1*	Centre *Do1*	Right	
	Up *Do2*	2 10	10 2	11 Max 1	Act: 5 Bel: 16
	Middle *Do2*	3 9	4 8	10 L1 2	Act: 35 Bel: 34
	Down	5 7	8 4	Eq 9 L2 3 L3 D1	Act: 60 Bel: 50
		Act: 2.5 Bel: 11.5	Act: 7.5 Bel: 19.75	Act: 90 Bel: 68.75	

In treatments BABAF and ABF, the Down-Left Payoff was changed by (6,6).

Game 2R

Row \ Column	Left *Do3*	Centre *Do1*	Right	
Up	7 L2 5 D1	7 5	8 Eq 4 L3	Act: 95 Bel: 66.5
Middle *Do2*	10 L1 Max 2	1 11	9 3	Act: 5 Bel: 20.25
Down *Do2*	11 1	2 10	9 3	Act: 0 Bel: 13.25
	Act: 30 Bel: 45.75	Act: 0 Bel: 9	Act: 70 Bel: 45.25	

In treatments BABAF and ABF, the Up-Left Payoff was changed by (6,6).

Game 2C

Row \ Column	Left *Do2*	Centre	Right *Do2*	
Up *Do3*	1 11	8 L1 4 D1	5 Max 7	Act: 25 Bel: 42.25
Middle *Do1*	8 4	8 4	11 1	Act: 0 Bel: 12.75
Down	5 7	Eq 7 L2 5 L3	5 7	Act: 75 Bel: 45
	Act: 5 Bel: 11.75	Act: 87.5 Bel: 57.25	Act: 7.5 Bel: 31	

In treatments BABAF and ABF, the Down-Left Payoff was changed by (6,6).

Game 3R

Column

Row	Left *Do3*	Centre	Right *Do1*	
Up	7 5	Eq 8 L2 4 L3 D1	7 5	Act: 92.5 Bel: 66.25
Middle *Do1*	9 3	11 1	8 4	Act: 2.5 Bel: 8.25
Down *Do2*	9 3	9 L1 Max 3	1 11	Act: 5 Bel: 2.55
	Act: 15 Bel: 27.25	Act: 72.5 Bel: 63.25	Act: 12.5 Bel: 9.5	

In treatments BABAF and ABF, the Up-Left Payoff was changed by (6,6).

Game 3C

Column

Row	Left *Do1*	Centre *Do2*	Right	
Up *Do1*	3 9	11 1	4 8	Act: 0 Bel: 6.25
Middle	2 10	L1 2 10	Eq 3 L3 9 D1	Act: 85 Bel: 73.25
Down *Do3*	4 8	Max 1 11	5 L2 7	Act: 15 Bel: 20.5
	Act: 0 Bel: 20.35	Act: 12.5 Bel: 26.39	Act: 87.5 Bel: 53.27	

In treatments BABAF and ABF, the Down-Right Payoff was changed by (6,6).

Game 4R

Column

		Left	Centre *Do2*	Right *Do4*	
	Up *Do1*	8 4	10 2	11 1	Act: 0 Bel: 6
Row	Middle *Do3*	7 5	1 11	Max 8 4	Act: 12.5 Bel: 28.25
	Down	Eq 5 L2 7 L3 D1	4 8	L1 2 10	Act: 87.5 Bel: 66.25
		Act: 87.5 Bel: 53	Act: 0 Bel: 14	Act: 12.5 Bel: 33	

In treatments BABAF and ABF, the Middle-Left Payoff was changed by (6,6).

Game 4C

Column

		Left	Centre *Do3*	Right *Do1*	
	Up	Eq 5 L2 7 L3	4 8	3 9	Act: 67.5 Bel: 50.25
Row	Middle *Do4*	L1 7 D1 5	Max 1 11	3 9	Act: 32.5 Bel: 40.75
	Down *Do2*	9 3	11 1	2 10	Act: 0 Bel: 9
		Act: 90 Bel: 67.75	Act: 2.5 Bel: 21.75	Act: 7.5 Bel: 10.5	

In treatments BABAF and ABF, the Middle-Left Payoff was changed by (6,6).

Game NR

Column

Row		Left	Centre	Right	
	Up	4 8	7 5	Max 11 1	Act: 2.5 Bel: 18.25
Row	Middle	7 5	Eq 7 5	L1 7 D1 5	Act: 92.5 Bel: 60.25
	Down	L3 10 2	7 5	L2 5 7	Act: 5 Bel: 21.5
		Act: 7.5 Bel: 16.75	Act: 52.5 Bel: 45.5	Act: 40 Bel: 37.75	

In treatments BABAF and ABF, the Down-Right Payoff was changed by (6,6).

Game NC

Column

Row		Left	Centre	Right	
	Up	11 1	5 L3 7	9 3	Act: 2.5 Bel: 16.25
Row	Middle	8 4	8 L2 4	Eq 8 4	Act: 72.5 Bel: 53.5
	Down	Max 4 8	10 2	L1 9 D1 3	Act: 25 Bel: 9
		Act: 5 Bel: 22.5	Act: 20 Bel: 28	Act: 75 Bel: 49.5	

In treatments BABAF and ABF, the Up-Centre Payoff was changed by (6,6).

6 Instructions for Chapter 5

WELCOME TO OUR EXPERIMENT!

This is a serious scientific experiment and, as such, no talking, looking around or walking around will be permitted. If you have any questions or need any assistance, please raise your hand and an experimenter will come to you. If you talk, exclaim out loud, etc, YOU WILL BE ASKED TO LEAVE AND YOU WILL NOT BE PAID. Thank you.

This is an experiment on individual decision making. The ESRC Centre for Evolutionary Learning and Social Evolution (ELSE) has provided the funds for this experiment. You will be paid £5 (five pounds) for having arrived on time. Additionally, if you follow the instructions and pass an UNDERSTANDING TEST you will be allowed to continue in the experiment. Once in the experiment, depending on your decisions you may earn a considerable additional amount of money. This additional amount will be determined both by your decisions and by those of other participants in the experiment. Before making your decisions, you will be informed about how your earnings and the other participants' earnings depend on your and their decisions. All that you earn is yours to keep, and will be paid to you in private, in cash, after today's session.

We need 20 people for this session. Thus, if more than 20 people pass the UNDERSTANDING TEST, some of you will be asked not to participate in the experiment but to help the experimenter as "assistants". These assistants will check that everything is done as explained in the instructions. The assistants will be paid the average of the payments of the 20 participants in the experiment.

In this experiment, 10 participants will belong to group A (to whom we will refer as "A") and 10 participants will belong to group B (to whom we will refer as "B"). All participants have to take decisions from a table they will be presented. For each table, each participant in group A will be anonymously matched with one participant in group B.

Participants in group A will be presented with a TABLE. For this table, participants in group A will take a decision. Afterwards, participants in group B will be presented with the same table and, knowing what their matched participant in group A decided, they will make another decision. Together, the two decisions determine the number of POUNDS each of you earns, which may be different.

The table in the next page shows an illustrative example. IT IS ONLY AN ILLUSTRATION. The tables you will see during the experiment will be different from this one. AS YOU LOOK AT THIS TABLE, PLEASE CONTINUE READING THIS HANDOUT FOR INSTRUCTIONS ON HOW TO UNDERSTAND THE TABLE:

B

		LEFT	CENTRE	RIGHT
	UP	9 1	8 2	7 3
A	MIDDLE	6 4	5 5	4 6
	DOWN	3 7	2 8	1 9

In the actual experiment, A will be shown tables like this one (but with different numbers), and asked to choose one decision ("**UP**", "**MIDDLE**" or "**DOWN**"). After A takes his/her decision, the participant from B with whom they are matched for each table will learnt what decision A took in that table and will be asked to choose his/her decisions ("**LEFT**", "**CENTRE**" or "**RIGHT**").

The combination of A's decision and B's decision determines the number of pounds they receive. These numbers are whole numbers ranging from 1 to 11.

The number of pounds A receives appears in the lower left corner of each cell of the table.

The number of pounds B receives appears in the upper right corner of each cell of the table.

To interpret the table, consider the results of the possible combinations of decisions.

-If A chooses **UP** and then B chooses **LEFT**, A earns 1 Pound and B earns 9 Pounds.
-If A chooses **UP** and then B chooses **CENTRE**, A earns 2 Pounds and B earns 8 Pounds.
-If A chooses **UP** and then B chooses **RIGHT**, A earns 3 Pounds and B earns 7 Pounds.
-If A chooses **MIDDLE** and then B chooses **LEFT**, A earns 4 Pounds and B earns 6 Pounds.
-If A chooses **MIDDLE** and then B chooses **CENTRE**, A earns 5 Pounds and B earns 5 Pounds.
-If A chooses **MIDDLE** and then B chooses **RIGHT**, A earns 6 Pounds and B earns 4 Pounds.
-If A chooses **DOWN** and then B chooses **LEFT**, A earns 7 Pounds and B earns 3 Pounds.
-If A chooses **DOWN** and then B chooses **CENTRE**, A earns 8 Pounds and B earns 2 Pounds.
-If A chooses **DOWN** and then B chooses **RIGHT**, A earns 9 Pounds and B earns 1 Pound.
Please be sure you understand this table. Raise your hand if you would like further explanation. Otherwise, please start with the Understanding Test in the next page. Please raise your hand once you have finished the Understanding Test.

UDERSTANDING TEST

You will now take a short UNDERSTANDING TEST. After you have finished the TEST, it will be graded and you will ONLY be allowed to continue in the experiment if you have answered ALL the QUESTIONS CORRECTLY. If one or more of your answers is not correct, we will ask you to be our assistant and to check that everything proceeds as explained in the instructions. Notice that even if all your answers are correct, you may be asked to be our assistant.
This test has 5 questions. After you have answered all 5 questions, please re-check your answers. Please raise your hand when you are finished so as we can grade this test.

			B	
		LEFT	CENTRE	RIGHT
	UP	6 2	3 7	4 5
A	MIDDLE	8 9	9 6	2 4
	DOWN	1 1	5 3	7 3

Using the table above, please answer the following questions.

Questions:

1. If A chooses **MIDDLE** and afterwards B choosess **RIGHT**, how many Pounds will A earn? __

2. If A chooses **UP** and afterwards B choosess **LEFT**, how many Pounds will B earn? _______

3. If A chooses **UP** and afterwards B choosess **RIGHT**, how many Pounds will A earn? _______

4. If A chooses **DOWN** and afterwards B choosess **CENTRE**, how many Pounds will A earn? __

5. If A chooses **DOWN** and afterwards B choosess **LEFT**, how many Pounds will B earn? ____

YOU HAVE JUST COMPLETED THE TEST.
Please re-check your answers and raise your hand when you are done.

INSTRUCTIONS

There are 20 participants in this experiment. We have randomly divided the 20 participants in two groups of 10 participants ("group A" and "group B"). Everyone has been recruited for this experiment using the same procedure and everyone has been assigned to one of the two groups randomly.

We are going to show you 10 different tables, similar to the one you have already seen.

For each of the 10 tables you receive a different answer sheet. In each answer sheet you will have to make a decision. Below we explain how to make your choices and how you will be paid for them.

First, participants of group A will circle their decision (UP, MIDDLE or DOWN) in each of the 10 tables.

After A have made all their choices, their answers sheets will be collected.

Then, participants in group B will receive 10 answer sheets, each one corresponding to a different table and coming from a different participant from group A.

Therefore, participants in group B will know what the participant from group A with whom they are matched in each table has chosen for each table.

After receiving the answer sheets, participants in group B will choose between **"LEFT"**, **"CENTRE"** and **"RIGHT"** in each of the 10 tables. These choices, together with the choice by the participant in group A, will select a cell in each of the 10 tables.

Notice that for each of the 10 tables, you will be anonymously and randomly matched with one of the 10 participants from the other group.

YOU HAVE BEEN MATCHED WITH A DIFFERENT PARTICIPANT IN EACH TABLE.

NO PARTICIPANT IN THIS EXPERIMENT WILL KNOW WHO THEY ARE MATCHED WITH FOR ANY PARTICULAR TABLE.

NO PARTICIPANT IN THIS EXPERIMENT WILL KNOW THE CHOICE MADE BY PARTICIPANTS WITH WHOM THEY ARE NOT MATCHED.

Example

In the table below A circles "DOWN" to indicate that DOWN is his choice. After observing A's choice, B circles "RIGHT" to indicate that RIGHT is his choice:

		B		
		LEFT	CENTRE	RIGHT
	UP	5 2	4 8	3 4
A	MIDDLE	7 5	4 11	3 7
	DOWN	9 3	11 1	8 5

Caution: The numbers used in this example were selected arbitrarily. They are NOT intended to suggest how anyone might choose in any situation.

Below we explain how we will pay you according to your choices.

PAYMENTS

After the experiment is finished, we will randomly select ONE table from which all payments to all participants will be done. This table will be selected using a bingo urn with 10 numbered balls. The number on the ball selected determines for which of the 10 tables all participants are paid.

Participants from group A will be paid a number of pounds equal to the number that appears in the left down corner of the cell chosen by them and their matched participant from group B in the selected table.

Participants from group B will be paid the amount of pounds that appears in the upper right corner of the cell chosen by them and their matched participant from group A in the selected table.

YOU BELONG TO GROUP A (B)

You (Your matched participant in the table selected) will be paid the sum of two things:

- £5 for arriving on time.
- The amount of pounds indicated in the lower left corner in the chosen cell of the selected table.

Your matched participant in the table selected (You) from group B will be paid:
- £5 for arriving on time

- The amount of pounds that appears in the upper right corner in the chosen cell of the selected table.

FINAL INSTRUCTIONS

We will wait until all participants in group A have finished choosing in the 10 tables, to give the answer sheets to participants in group B. Please take some time to think and check your answers. We will allow each participant a maximum of 20 minutes to answer all questions. **Please, if you finish before time raise your hand and we will collect your answers.**
You are asked to remain in your seat quiet until the experiment is finished.

You have been given an identification number. **Please write this number at the top of each of your answer sheets (where it says "GROUP A (B) IDENTIFICATION NUMBER") and keep the number.** You will need this number to be paid.

While we calculate the payments you will be asked to fill in an anonymous questionnaire. After we have done the calculations, you will be asked to come with the questionnaire and your identification number to a room where you will be paid your earnings in cash and in private.

PLEASE WAIT UNTIL THE EXPERIMENTER TELLS YOU TO START

(Please raise your hand if there are any doubts with these instructions, and we will answer them privately)

7 The Games in Chapter 5

Below we show each of the ten games subjects played in "Unfair" treatments. Below each game we indicate the cell that was changed to create the "Fair" treatments. Additionally, we indicate the percentage of subjects who played each action, both for first movers ("First") and second movers ("Second").

Game 1R

	Left	Centre	Right	
Up	9 3	8 4	7 5	First: 0 Second: 0
Middle	7 5	5 7	5 7	First: 5 Second: 0
Down	3 9	3 9	4 Equilibrium 8	First: 95 Second: 100
	First: 10 Second: 10	First: 0 Second: 0	First: 90 Second: 90	

In the "Fair" treatments, the Middle-Left Payoff was changed by (6,6).

Game 1C

	Left	Centre	Right	
Up	2 10	10 2	11 1	First: 0 Second: 0
Middle	3 9	4 8	10 2	First: 10 Second: 0
Down	5 7	8 4	9 Equilibrium 3	First: 90 Second: 100
	First: 5 Second: 0	First: 0 Second: 10	First: 95 Second: 90	

In the "Fair" treatments, the Down-Left Payoff was changed by (6,6).

Game 2R

	Left	Centre	Right	
Up	7 5	7 5	8 Equilibrium 4	First: 100 Second: 95
Middle	10 2	1 11	9 3	First: 0 Second: 5
Down	11 1	2 10	9 3	First: 0 Second: 0
	First: 10 Second: 15	First: 5 Second: 0	First: 85 Second: 85	

In the "Fair" treatments, the Up-Left Payoff was changed by (6,6).

Game 2C

	Left	Centre	Right	
Up	1 11	8 4	5 7	First: 5 Second: 0
Middle	8 4	8 4	11 1	First: 0 Second: 0
Down	5 7	7 Equilibrium 5	5 7	First: 95 Bel: 100
	First: 0 Second: 0	First: 100 Second: 100	First: 0 Second: 0	

In the "Fair" treatments, the Down-Left Payoff was changed by (6,6).

Game 3R

	Left	Centre	Right	
Up	7 5	8 Equilibrium 4	7 5	First: 100 Second: 100
Middle	9 3	11 1	8 4	First: 0 Second: 0
Down	9 3	9 3	1 11	First: 0 Second: 0
	First: 5 Second: 10	First: 90 Second: 90	First: 5 Second: 0	

In the "Fair" treatments, the Up-Left Payoff was changed by (6,6).

Game 3C

	Left	Centre	Right	
Up	3 9	11 1	4 8	First: 0 Second: 0
Middle	2 10	2 10	3 Equilibrium 9	First: 85 Second: 100
Down	4 8	1 11	5 7	First: 15 Second: 0
	First: 0 Second: 0	First: 5 Second: 10	First: 95 Second: 90	

In the "Fair" treatments, the Down-Right Payoff was changed by (6,6).

Game 4R

	Left	Centre	Right	
Up	8 4	10 2	11 1	First: 0 Second: 0
Middle	7 5	1 11	8 4	First: 10 Second: 0
Down	5 Equilibrium 7	4 8	2 10	First: 90 Second: 100
	First: 100 Second: 95	First: 0 Second: 0	First: 0 Second: 5	

In the "Fair" treatments, the Middle-Left Payoff was changed by (6,6).

Game 4C

	Left	Centre	Right	
Up	5 Equilibrium 7	4 8	3 9	First: 90 Second: 100
Middle	7 5	1 11	3 9	First: 5 Second: 0
Down	9 3	11 1	2 10	First: 5 Second: 0
	First: 95 Second: 95	First: 0 Second: 0	First: 5 Second: 5	

In the "Fair" treatment, the Middle-Left Payoff was changed by (6,6).

Game NR

	Left	Centre	Right	
Up	4 8	7 5	11 1	First: 0 Second: 10
Middle	7 5	7 Equilibrium 5	7 5	First: 100 Second: 35
Down	10 2	7 5	5 7	First: 0 Second: 55
	First: 0 Second: 25	First: 85 Second: 55	First: 15 Second: 20	

In the "Fair" treatments, the Down-Right Payoff was changed by (6,6).

Game NC

	Left	Centre	Right	
Up	11 1	5 7	9 3	First: 0 Second: 5
Middle	8 4	8 4	8 Equilibrium 4	First: 100 Second: 90
Down	4 8	10 2	9 3	First: 0 Second: 5
	First: 5 Second: 20	First: 0 Second: 60	First: 95 Second: 20	

In the "Fair" treatments, the Up-Centre Payoff was changed by (6,6).

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